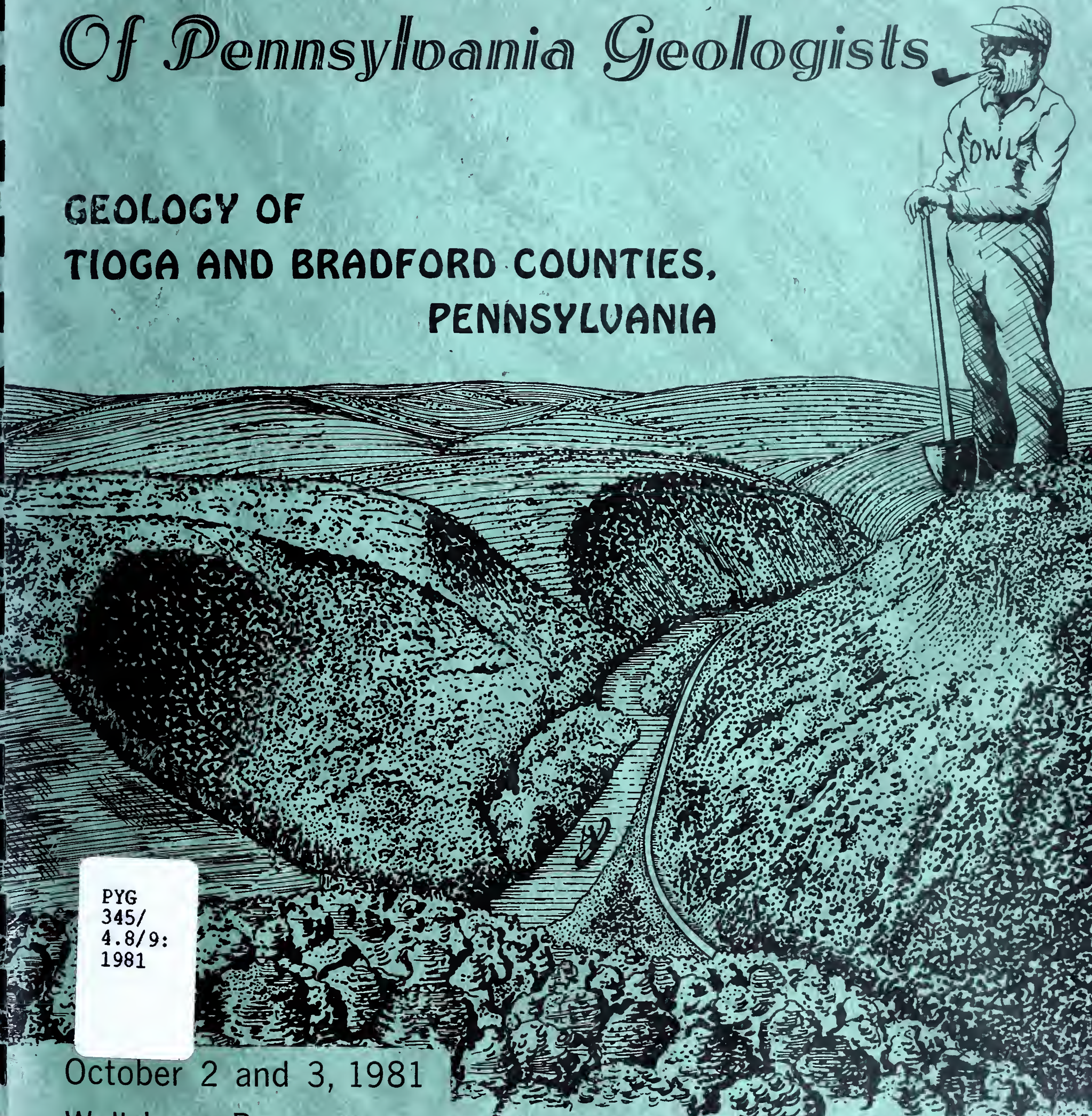
GUIDEBOOK

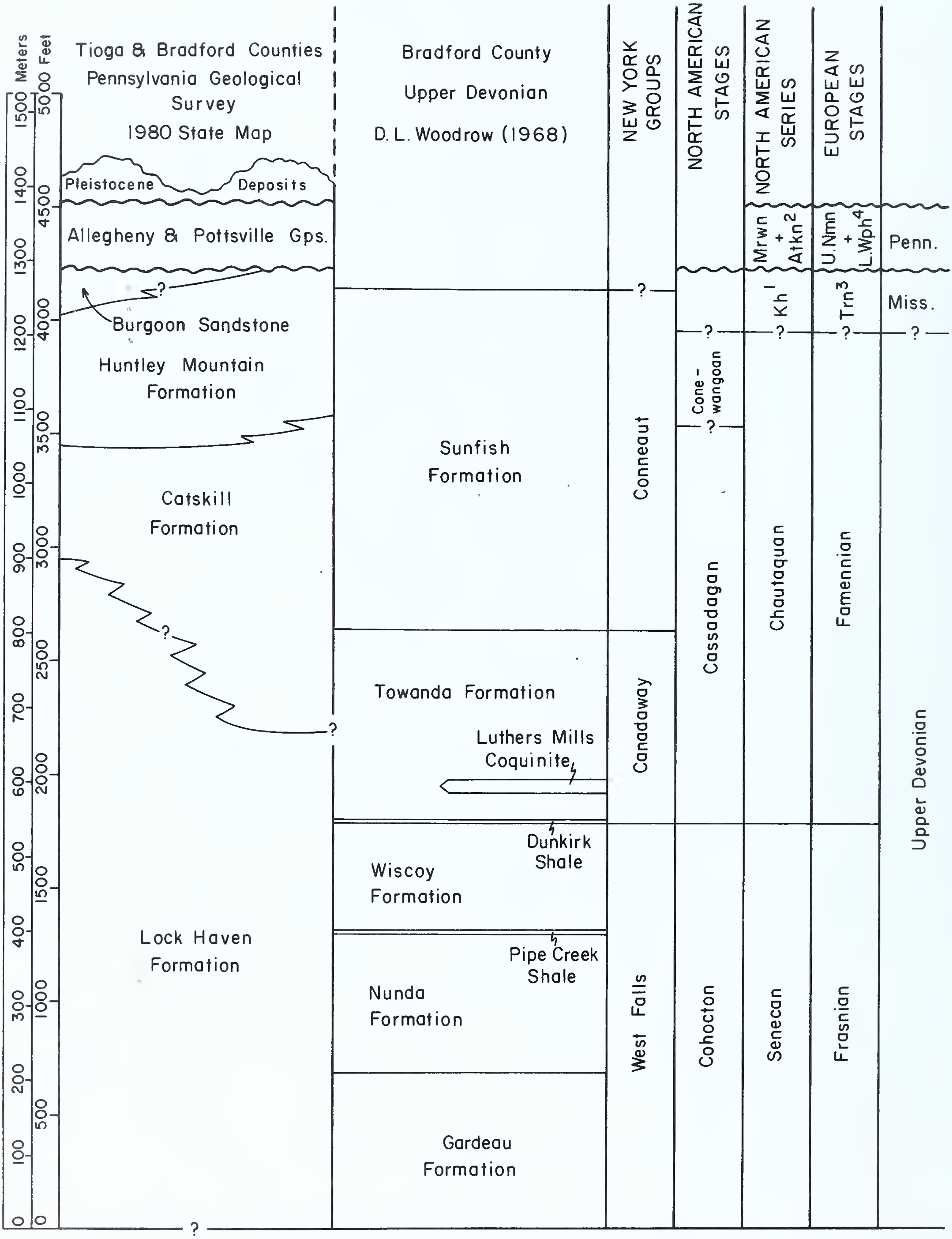
46th. Annual Field Conference Of Pennsylvania Geologists



GEOLOGY OF TIOGA AND BRADFORD COUNTIES, PENNSYLVANIA

October 2 and 3, 1981
Wellsboro, Pa.

Hosts: Pa. Geological Survey
Mansfield State College



[1] Kh = Kinderhookian ; [2] Mrwn = Morrowan, Atkn = Atokan;
[3] Trn = Tournaisian ; [4] U. Nmn. = Upper Namurian , L. Wph = Lower Westphalian

Guidebook for the

46th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

GEOLOGY OF TIOGA AND BRADFORD COUNTIES
PENNSYLVANIA

Leaders: T. M. Berg, Pennsylvania Geological Survey
G. H. Crowl, Ohio Wesleyan University
W. E. Edmunds, Consultant, Camp Hill, PA
P. B. Luce, Mansfield State College
W. D. Sevon, Pennsylvania Geological Survey
J. P. Wilshusen, Pennsylvania Geological Survey
D. L. Woodrow, Hobart and William Smith Colleges
H. A. Pohn U. S. Geological Survey

October 2 and 3, 1981

Hosts: Pennsylvania Geological Survey
Mansfield State College

Headquarters Hotel: The Penn-Wells Hotel, Wellsboro, PA

Cover: Pine Creek gorge, the Grand Canyon of Pennsylvania.
Design: W. D. Sevon Art work: A. E. VanOlden

Frontispiece: Columnar diagram showing surface stratigraphic nomenclature and relations in the Field Conference area.

Inside Back Cover: Map showing generalized bedrock geology, field trip routes, and stop locations for the Field Conference.

Guidebook distributed by:

Field Conference of Pennsylvania Geologists
c/o Department of Environmental Resources
Bureau of Topographic and Geologic Survey
P. O. Box 2357
Harrisburg, PA 17120

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ADDENDUM

GEOLOGY OF TIOGA AND BRADFORD COUNTIES, PENNSYLVANIA

INTRODUCTION

This 46th Annual Field Conference of Pennsylvania Geologists has as a principal theme: "Something for Everyone." It's been a while since a conference was held that had no specific theme other than the general geology of a region. This trip is presented with the hope that those attending will return home with their systems recharged, their geological acumen sharpened, and their appreciation of the fun of being a geologist invigorated. The Tioga County-Bradford County region was selected for a field conference for two reasons. First--Those who did the reconnaissance geology for the new 1980 state geologic map fell in love with the area. Second--In the 46-year history of the Field Conference, no trip has ever touched upon the geology of the north-central counties of Potter, Tioga and Bradford. These northern tier Pennsylvania counties are some of the most scenic in the Commonwealth. Except for the work done by Woodrow (1968), Denny (1956), and Denny and Lyford (1963), very little recent detailed geologic work has been published for this region. It is hoped that this guidebook will serve as a starting point for future detailed surficial and bedrock mapping and economic/environmental geologic studies in this part of Pennsylvania.

PREVIOUS GEOLOGIC INVESTIGATIONS

The first comprehensive report on the geology of the Tioga-Bradford County region was given by Rogers (1858, v. 1, p. 294-312; v. 2, p. 511-527) for the First Pennsylvania Geological Survey. During the second geological survey of Pennsylvania, the two counties were mapped and described from the viewpoint of each anticlinal valley and synclinal mountain; considerable detail was devoted to each coal-producing basin (Sherwood and others, 1878). Williams and Kindle (1905) and Willard (1932, 1939) elaborated on the invertebrate fossils of the Tioga-Bradford region. Fuller and Alden (1903a, 1903b) mapped the geology of the Gaines and Elkland/Tioga 15-minute quadrangles and brought a stratigraphic nomenclature into that part of Pennsylvania that remained essentially unchanged until the work on the 1980 state geologic map was begun. Their mapping was quite good, the only significant error being their northward extension of the Mauch Chunk Formation beyond its natural limits. For many years the "Patton" red shales below the Burgoon Sandstone were miscorrelated with the Mauch Chunk Formation red beds. In the early 1930's, several reports of the Fourth Pennsylvania Geological Survey dealing mainly with natural gas resources in the Tioga region were released. These reports were authored by Cathcart and Willard (1931), Ashley and others (1931), Ashley and Cathcart (1932), Fettke and Willard (1931), and Cathcart and Myers (1934). They contain discussions in varying detail of both subsurface and surface stratigraphy as well as regional structure.

The Blossburg coal district (Tioga County) and outlier coal fields in Bradford County were summarized by Sisler (1926); further details on the history of coal mining in these two counties is given in the section on economic geology in this guidebook. Chadwick (1933a, 1933b, 1935) elucidated the lithostratigraphic framework of the Upper Devonian and Mississippian of northern Pennsylvania and New York, and demonstrated the need for distinction between lithostratigraphic and chronostratigraphic units in the succession. Caster (1934) formulated the concepts of magnafacies and parvafacies in which

magnafacies are complete rock units, and parvafacies are defined by both time lines and lithologic definition. He applied his facies concepts to the Upper Devonian and Mississippian of northern Pennsylvania, recognizing seven magnafacies across this region. His thinking was a guiding light to the Pennsylvania Survey's handling of the stratigraphy of the northern part of the state during compilation of the new state map.

Ingham (1951) prepared a map showing the structural geology of the northern plateau region, and indicated the location of wells and gas fields. Fettke (1954) refined and updated the structure contour mapping of the entire plateau region, including Tioga County and most of Bradford County. Cate (1962) revised Fettke's structural mapping for most of Tioga County and a small part of Bradford County, using the top of the Oriskany Formation as a datum.

McCauley (1961) documented the occurrence of several uranium prospects near New Albany southern Bradford County.

The Cedar Run quadrangle was mapped by Colton (1963a); this geologic map in southwestern Tioga County (and northern Lycoming County) was the first detailed mapping accomplished since the work done by the Second Pennsylvania Survey in the late 1800's. At the same time, Colton (1963b) detailed the Late Devonian and Mississippian rock sequence of north-central Pennsylvania, and discussed details of potential stratigraphic correlation in this region. His preliminary stratigraphic subdivisions provided a sound basis for extrapolation and reconnaissance revision for the new state geologic map. Woodrow (1963) recognized several new stratigraphic subdivisions during reconnaissance mapping of the Sayre and Towanda 15-minute quadrangles in Bradford County. These were utilized in later detailed mapping. Sutton (1963) recognized black shale tongues in the Upper Devonian succession of south-central New York, and considered these key beds to be nearly isochronic. He postulated that these shales were useful in subdividing the Upper Devonian marine sequence, and that they penetrated the Catskill lithofacies eastward.

With a better understanding of surface stratigraphy in hand, Colton (1967) prepared a structure map of portions of Lycoming, Clinton, Tioga and Potter Counties. He utilized a persistent conglomerate zone in the sub-Burgoon Mississippian sequence, as well as the base of the Burgoon Sandstone itself. This structure map was most useful in compilation of the new state geologic map. Woodrow (1968) mapped the bedrock geology of the bulk of northern and central Bradford County, and introduced stratigraphic nomenclature as utilized in New York. Woodrow also elaborated in considerable detail on the depositional patterns, sedimentary cycles, and structure of the Upper Devonian of this region. The regional distribution of flagstone and its physical properties in the Endless Mountains region (including Tioga and Bradford Counties) were summarized by Glaeser (1969).

Fergusson and Prather (1968) discussed subdivision of the Salina Group of Pennsylvania, and correlated Salina units with other parts of the state. Unusually thick salt deposits occurring in Tioga and Bradford Counties were thoroughly illustrated. The 2500-foot thickness of Salina Group rocks in north-central Pennsylvania was also treated in detail by Rickard (1969), and

relationships to New York, Ohio, Michigan, and Ontario were elaborated.

Wright (1973) described the subsurface distribution of the Tully Limestone in New York and northern Pennsylvania; a relatively thick development (120 ft) of Tully was indicated in central Bradford County, thinning to 40 ft at the eastern border of Bradford County. More gradual westward thinning of the Tully to approximately 50 ft in the northwest corner of Tioga County was shown.

Berg and Edmunds (1979) revised Upper Devonian-Lower Mississippian stratigraphic nomenclature of north-central Pennsylvania by deleting "Pocono" and "Oswayo" usage, and naming the new "Huntley Mountain" Formation. This new name is applied to the transition between the Catskill Formation and the Burgoon Sandstone.

Crowl and Sevon (1980) remapped the deposits forming the border of glaciation of Late Wisconsinan age across northeastern and north-central Pennsylvania. This mapping of the glacial border crosses the southwestern portion of Tioga County.

Pohn (1981) recently applied the technique of contouring areas of equal joint spacing to locate fault zones in the Allegheny Plateau. Much of his data was collected from the western half of Bradford County.

ACKNOWLEDGEMENTS

The Field Conference of Pennsylvania Geologists and the leaders of this 46th annual meeting wish first of all, to thank the citizens of Tioga and Bradford Counties for their hospitality and friendly welcome to us as we prepared for this conference. Mr. Louis Case, R. D. Towanda, has given permission to visit the quarry on his property at Stop 1 where the Luthers Mills coquinite is exposed. Mr. Duane Pepper, R. D. Monroeton, has kindly provided access to his property at Stop 3 where the Lock Haven-Catskill transition beds are exposed. Mr. Robert Mott, R. D. Troy, has kindly allowed us to examine the outcrops of Huntley Mountain Formation along the waterfalls at Stop 4. Mr. Richard Mase, President of Antrim Mining, Inc., Blossburg, has permitted the Field Conference to enter the Anna S. coal mine property at Stop 8. Mr. Bud Benson, R. D. Mansfield, has generously allowed access to his property to examine the Mansfield iron ore at Stop 9. Mr. Benson also gave permission to excavate and expose the ore bed prior to the conference. Information about the Tioga-Hammond Lakes Flood Control Project and associated engineering works has been generously provided by: (1) the U. S. Army Corps of Engineers, Baltimore District; (2) Pennsylvania Department of Transportation, Engineering District 3-0; (3) Gannett Fleming Corddry and Carpenter, Inc.; and (4) Gilbert Associates, Inc. The authors of this guidebook extend special thanks to: Dick Royer and Wes Franklin of the Corps of Engineers; Paul Solomon of the Pennsylvania Department of Transportation; and Jim Knight of Gannett Fleming Corddry and Carpenter. Rich Koeppel, Resource Manager of Tioga-Hammond and Cowanesque Lakes has extended us the generous hospitality of the Corps of Engineers during our visit to the Tioga-Hammond facility (Saturday lunch and Stop 12).

Mansfield State College provided a Faculty Project Grant to P. B. Luce for geologic research in the Tioga County-Bradford County area. This grant permitted Mr. Doug Kanora and Mr. Richard Biery to serve as field and lab assistants.

Discussions with the following persons (and loan of photographs by them) regarding the mineral economic history of the region are gratefully acknowledged: Mr. George C. Barden, Mrs. Allen W. Howland, Mr. Gale P. Largey, Mr. Elwyn S. Lewis, and Mr. Kurt Lytle.

The Wellsboro Chamber of Commerce has provided general literature regarding attractions in the Field Conference area, and generously agreed to host the pre-meeting orientation session, providing refreshments and snacks. Ms. Cindy Hulflander of the Bradford County Commissioners' Office helped in scheduling the area used for the Friday lunch stop at Sunfish Pond County Park. Mr. Lee Cleveland of the Bradford County Assessors Office was most helpful in locating names of property owners.

In assembling information about the Pennsylvanian strata and Pleistocene deposits at Stop 8, the following persons provided much useful data and helpful discussion: Mr. Joseph Aichholz, Jr. and Mr. Neil Hedrick of Antrim Mining, Inc.; Mr. Edwin F. Koppe, Consulting Geologist, Harrisburg; and Mr. Boyer Kantz, Consulting Engineer, Wellsboro.

Mr. Fred Wade, Warwick Silica, Inc. at Morris generously permitted access to the active quarry in the Pottsville Formation sandstone near Stop 8, and provided information regarding present utility of the sandstone product.

The following geology students at Mansfield State College graciously volunteered to serve as road guards, traffic controllers, and general "shepherds" for Field Conference participants: Mr. Richard Biery, Mr. Grant Emory, Mr. Douglas Kanora, and Mr. Jerry Smith. Their help is greatly appreciated.

We wish to thank Mrs. Christine Dodge, Editor for the Pennsylvania Geological Survey, for her advice and assistance during preparation of the guidebook. We acknowledge with much gratitude, the work done by Mr. Jack Kuchinski, Mr. Albert Van Olden, Mr. Jim Dolimpio, and Mr. Geary Sarno of the Editorial Section of the Pennsylvania Survey, in drafting many of the diagrams for the guidebook. We also wish to thank Dr. Donald Hoskins, Mrs. Marjorie Steel, and Mrs. Janet Wotring of the Pennsylvania Survey for their handling of logistics for the Field Conference. Mrs. Sandra Blust, Librarian of the Pennsylvania Survey was most helpful in providing research materials and literature during writing of the guidebook.

Last, and certainly not least, we wish to express our grateful appreciation to Miss Valerie Lawson, Secretaty for the Geologic Mapping Division of the Pennsylvania Survey, who typed the manuscript for this guidebook.

SUBSURFACE STRATIGRAPHY

by
T. M. Berg

INTRODUCTION

The following summary of subsurface stratigraphy is based mainly on statewide correlation work done over the past three years by the Pennsylvania Geological Survey for Project COSUNA (Correlation of Stratigraphic Units of North America - AAPG), and for "tight sand" designations for the Federal Energy Regulatory Commission (FERC). The COSUNA work was done by M. K. McInerney (now at West Virginia University) and T. M. Berg. The FERC correlations were assembled by members of the Geologic Mapping Division of the Pennsylvania Survey and J. A. Harper of the Oil and Gas Geology Division of the Pennsylvania Survey.

CAMBRIAN AND ORDOVICIAN

Based on extrapolation from the work of Wagner (1966, 1976), 700 ft or more of Middle Cambrian Pleasant Hill Formation should be present in the Tioga County-Bradford County region. The Pleasant Hill, a sandy limestone and calcareous shale grading upward to dark-gray limestone, is replaced toward Steuben County, New York, by dolomitic sandstone and sandy dolomite of the Theresa Formation. The Pleasant Hill may be underlain by Potsdam Sandstone or a lateral equivalent of the Waynesboro Formation. Depth to Precambrian basement in the Field Conference area is thought to range from about 16,000 ft in the northwest corner of Tioga County to about 25,000 ft in the southeast corner of Bradford County.

The Pleasant Hill Formation is probably overlain by approximately 450 ft of limestone, dolomite, and shale of the Middle to Upper Cambrian Warrior Formation. The Warrior probably grades laterally to the Potsdam Sandstone of western Pennsylvania (Wagner, 1976); the lateral equivalent to the north is within the Theresa Formation of New York (Wagner, 1966).

Approximately 1900 ft of Upper Cambrian Gatesburg Formation are thought to overlie the Warrior Formation. The Gatesburg is a mixture of sandstone and dolomite, and is divided vertically into the lower sandy member, the Ore Hill Member, the Upper sandy member, and the Mines Member. The Olin Sandstone is a prominent, medium to coarse grained, partly dolomitic sandstone subunit within the lower sandy member whose distribution appears to support the interpretation of growth faults in western Pennsylvania (Wagner, 1976). In the Harry P. Dewey #1 well drilled in 1974 by Amoco Production Company in western Tioga County, only 237 ft of Gatesburg was penetrated.

The Gatesburg is overlain by approximately 450 to 500 ft of Lower Ordovician Larke Formation dolomite having some traces of chert. A very thin limestone may be present near the top, representing a remnant of the Stonehenge Formation. The Larke/Stonehenge passes northeastward to the Tribes Hill Formation dolomite and limestone of New York (Wagner, 1966).

Approximately 425 ft of Nittany Formation dolomite unconformably overlie the Larke/Stonehenge; some vug-filling anhydrite occurs within the Nittany. About 2150 ft of Axeman and Bellefonte Formations comprising limestone and dolomite overlie the Nittany Formation in north-central Pennsylvania. Wagner (1966) details the lithic assemblages within these Lower Ordovician formations, and explains thier northwestward disappearance due to erosion and nondeposition. Total thickness of the "Beekmantown" Group (Larke through Bellefonte Formations) in the Harry P. Dewey #1 well is reported to be 1640 ft (Lytle, 1975).

The lateral equivalents of the Loysburg Formation, Hatter Limestone, Snyder Limestone, Benner Limestone, and Trenton Group are thought to comprise over 1000 ft of section in north-central Pennsylvania. In the Harry P. Dewey #1 well, the interval from "Trenton" down to "Beekmantown" is 1700 ft. Discrepancies and uncertainties concerning thicknesses may arise from confusion in regional correlations, and mixing of time-stratigraphic and rock-stratigraphic names (Wagner, 1966, p. 38). In the Pennsylvania Dept. of Forests and Waters tract 129 #1 well drilled by Consolidated Gas Supply Company in 1966 in Potter County, the interval from the top of the Trenton equivalent to the top of the upper member of the Bellefonte is 1225 ft.

Black, slightly calcareous and pyritic shale about 500 ft thick overlies the Trenton equivalent, and is called Utica Formation by some workers, or Antes Shale by others. Wagner (1966) suggests that the Utica may be laterally equivalent to part of the upper "Trenton" (Coburn Formation). The silty, dark-gray shales of the Reedsville Formation overlie the Utica and are probably on the order of 800 ft thick.

The Oswego Formation which is equivalent to the Bald Eagle Formation may be as thick as 1200 ft in north-central Pennsylvania. However, this succession of light-greenish-gray sandstones and interbedded dark-gray shales overlying the Reedsville is only 760 ft thick in the Pennsylvania tract 129 #1 well in Potter County.

The Queenston Formation overlies the Oswego and is equivalent to the Juniata Formation. In the Pennsylvania tract 129 #1 well, the red interbedded sandstones and shales of the Queenston are 990 ft thick. In the Harry P. Dewey #1 well in Tioga County, the top of the Queenston was reported at a depth of 8820 ft (Lytle, 1975).

A transition zone, possibly up to 150 ft thick separates the Queenston/Juniata from the overlying Tuscarora Sandstone. This transition zone includes white to reddish, fine to coarse grained sandstone and some thin, grayish red shale interbeds.

SILURIAN

Heyman (1977) established correlations (based mainly on interpretation of geophysical logs) for the Tully to Queenston interval in western Pennsylvania. One of his lines of sections connected the Pennsylvania tract 129 #1 well in Potter County and the A. W. Bennett #1 well drilled by the California Company in Sullivan County in 1951. The line between these two wells runs just south of the Tioga County-Bradford County area. Heyman shows the Medina Group (mostly Tuscarora Sandstone) overlying the Tuscarora-Juniata

transition, and thinning from 240 ft in the east to 190 ft in the west. He postulates an unconformity at the base of the Tuscarora in the Potter County well. The Medina Group in this area actually includes the Tuscarora Sandstone and an upper zone about 65 ft thick laterally equivalent to the Grimsby Sandstone. The Tuscarora Sandstone is light greenish gray with some pinkish tinge, and is fine to medium grained, having few coarse-grained zones. The Grimsby is a moderate red to orangish red, fine grained sandstone, having few moderate-red, silty interbedded shales. To the east, at the A. W. Bennett #1 well, Heyman (1977) indicates that the Castanea Member and an unnamed shale member occupy the upper 50 ft of the Medina Group.

Overlying the Medina, the Rose Hill Shale thins from approximately 1000 ft in Sullivan County to about 530 ft in Potter County. The Rose Hill is mostly greenish shale. In the lower third, interbeds of dolomite represent the Reynales Formation equivalent.

Heyman (1977) shows 20 ft of Keefer Sandstone followed by 100 ft of Rochester Shale overlying the Rose Hill Formation in the Sullivan County well. These two units together thin to about 90 ft in the Potter County well. Heyman indicates that the Rose Hill, Keefer, and Rochester comprise the Clinton Group. However, preferred usage combines the Keefer, Rochester, and overlying McKenzie Member into the Mifflintown Formation. The McKenzie is interbedded dark gray shale and medium dark gray limestone, having some zones of black limestone. Some oolitic zones may be present.

The Bloomsburg Formation overlies the McKenzie and thins from 455 ft in the Sullivan County well to 70 ft in the Potter County well. The Bloomsburg is moderately bright red shale, having few thin zones of dolomitic or calcareous siltstone, and some red sandstone. Rickard (1969) reports 525 ft of Bloomsburg red shale in the Blemle #1 well drilled by Pure Oil Company in Wilmot Township, Bradford County. Rickard further indicates that the lower red shales of the Vernon Shale are equivalent to the Bloomsburg Formation of Pennsylvania. The Vernon Shale is included in the Salina Group in New York.

The Salina Group which overlies the Bloomsburg, is equivalent for the most part to the Wills Creek and Tonoloway Formations of central Pennsylvania. Fergusson and Prather (1968) and Rickard (1969) have treated the Salina in considerable detail, and readers are referred to their work for specifics on this unusually thick salt- and anhydrite-bearing succession. Suffice it to say that the Salina is over 2500 ft thick beneath most of this Field Conference area, and is probably the thickest development in the Appalachian basin. Thinning occurs towards the northwest corner of Tioga County, where total Salina thickness is 2000 ft (Rickard, 1969). In the Pennsylvania Dept. of Forests and Waters tract 129 #1 well in Potter County, Heyman (1977) indicates that of the 2250-ft-thick evaporite-bearing sequence, the upper three fourths is "probably tectonically distorted."

DEVONIAN

The Silurian-Devonian systemic boundary is thought to be within the Keyser Formation which overlies the Tonoloway (or Salina). Heyman (1977) places the Keyser and overlying Corriganville Limestone, Mandata Shale, and Shriver Formation within the Helderberg Group. In the A. W. Bennett #1 well

in Sullivan County, the Keyser Formation (175 ft thick) is a light to medium dark brownish gray, slightly silty limestone which grades upward to light-gray, silty to very silty limestone; the Keyser is slightly dolomitic. In the same well, the Corriganville (60 ft thick) is a dark gray, argillaceous limestone having few cherty zones. The overlying Mandata Shale (160 ft thick) comprises dark gray to black, slightly silty, calcareous shale, having occasional stringers of limestone. The Shriver Formation at the top of the Helderberg is about 80 ft thick, and is dark gray limestone having thin interbeds of dark gray shale. Siliceous zones occur within the Shriver. Rickard (1969) shows the interval from the top of the Salina to the base of the Oriskany Group ("Cobleskill and Rondout Formations" and "Helderberg Group") thinning from 450 ft in southeastern Bradford County to 150 ft in northwestern Tioga County.

The Ridgeley Sandstone and "Oriskany" are almost synonymous, but not quite, and no attempt will be made here to untangle the nomenclature. See Heyman (1977) and Abel and Heyman (1981) for some elaboration. The Ridgeley which overlies the Shriver Formation, is white to very-light-gray, fine- to coarse-grained quartz sandstone having scattered quartz granules. It is slightly calcareous, and friable. Abel and Heyman (1981) show the Oriskany (Ridgeley) thinning from about 100 ft in south-central Bradford County to zero in northwestern Tioga County. The thinning is gradual across Bradford County, decreasing in a northwestern direction to about 60 ft in the western part of the county. The thinning is less regular across Tioga County; the isopach lines are more irregular, and an area of "no sand" is indicated in the Austinburg area.

Heyman (1977) indicates an unconformity at the top of the Ridgeley Sandstone. In the A. W. Bennett #1 well in Sullivan County, the Needmore Shale (220 ft thick) overlies the Ridgeley; the Selinsgrove Limestone (80 ft thick) overlies the Needmore. Together, the Needmore and Selinsgrove comprise the Onondaga Group. In the Pennsylvania Dept. of Forests and Waters tract 129 #1 well in Potter County, the Onondaga is shown by Heyman (1977) to have thinned to 20 ft of section above the Ridgeley. Jones and Cate (1957) show the Onondaga thinning from over 250 ft in southeastern Bradford County to less than 25 ft in central and western Tioga County. In the Potter County well, a thin zone of Tioga Bentonite (less than 5 ft) was encountered at the top of the Onondaga. This brown micaceous "shale" was first recognized as an important marker bed by Fettke (Fettke and Willard, 1931, p. 8); it was later recognized to be a bentonite having very widespread extent. The bentonite was named after the Tioga gas field in Tioga County. The Tioga has been observed over wide portions of the Allegheny Plateau from south-central and southwestern New York, through north-central, central, and southwestern Pennsylvania, Ohio, Maryland, West Virginia, Tennessee, and eastern Kentucky.

In work done for the Eastern Gas Shales Project, Piotrowski and Krajewski (1977) have established correlations of the Middle and Upper Devonian succession above the Tioga Bentonite across Tioga and Bradford Counties. Their correlations are based in large measure on identification of radioactive black shale zones using gamma-ray logs and some sample studies. They indicate that the black shales of the Marcellus Formation persist across the two-county area, and that the formation varies from 75 ft in the west to about 280 ft in the east. The overlying silty gray shales of the Mahantango Formation

vary from 585 ft in the west to about 1470 ft in the east.

The Tully Limestone (included by some workers as an uppermost member of the Mahantango Formation) persists across the Field Conference area. Wright (1973) shows a 120-ft thickness of Tully in central Bradford County, thinning to about 40 ft in the eastern part of the county. A gradual thinning of Tully to about 50 ft in the northwestern corner of Tioga County was indicated by Wright (1973). This distribution is generally consistent with isopachs drawn by Jones and Cate (1957), and appears to be consistent with the section drawn by Piotrowski and Krajewski (1977). The Burket Shale Member of the Harrell Formation is identified overlying the Tully across all of Tioga County, and into central Bradford County, where it is no longer recognizable in gamma-ray logs. No distinctive radioactive shale zones were recognized above the Burket. Piotrowski and Krajewski (1977) do not identify the Harrell Formation and overlying Brallier and Lock Haven Formations in their subsurface analysis in this area, but treat the post-Tully, post-Burket Upper Devonian informally, subdividing the succession into "zone A shale," overlain by undivided "zone D-B-B_0 sandstone." The "zone A shale" varies from 2060 ft in the west to about 3400 ft in the east. It is possible that the "zone A shale" is post-Burket Harrell and Brallier combined. The possible identification of Piotrowski and Krajewski's (1977) "zone D-B-B_0 sandstone" as equivalent to the Lock Haven Formation (and Catskill Formation, in part?) awaits further research.

It is worth noting that in further work done for the Eastern Gas Shales Project, Piotrowski and Harper (1979) say that the Dunkirk radioactive shale is limited to northwestern Pennsylvania. This conclusion contrasts with work done by Woodrow (1968) who believes that the Dunkirk Shale persists into Bradford County. Perhaps discussions arising during this Field Conference will shed light on these two different interpretations.

UPPER DEVONIAN SEDIMENTOLOGY AND STRATIGRAPHY

by
W. D. Sevon and D. L. Woodrow

INTRODUCTION

Throughout most of the Paleozoic, much of what presently constitutes the eastern half of North America was part of an inland sea which intermittently received clastic sediment from an eastern source area. The Appalachian basin was the central focus of this sedimentation.

The largest integrated wedge of clastic sediment in this basin was deposited by the Catskill delta system during the Middle and Upper Devonian. The term "delta system" as used here refers to multiple contiguous deltas operating in the same sedimentary basin at approximately the same time. The Catskill delta system is also a tectonic delta complex in the sense defined by Friedman and Johnson (1966, p. 185-186) for New York State and used by Humphreys and Friedman (1975, p. 369-370) in Pennsylvania: "a deltaic complex built into a marine basin contiguous to an active mountain front and dominated by orogenic sandstone derived from the nearby tectonic highland."

Rocks resulting from deposition by this delta system have been a source of fascination to several generations of geologists. In part, this is due to their ease of access and modest deformation, but it is mainly due to their characteristics. Stratigraphers and sedimentologists have looked to these rocks for instruction about the temporal plan of and sedimentary processes effective in a Paleozoic delta. It was the rocks of the Catskill delta to which the concepts of facies were first applied in North America (Chance, 1880, p. 107-115, especially, plate VIII). (To cite a 'first' is always dangerous, but Chance was at least one of the earliest of those thinking along this line and he is certainly the most unsung.) Economic geologists have been searching for petroleum and natural gas in the marine part of the delta for more than a century, and the anticlinal theory of exploration was developed to sharpen that search. Petrographers have long drawn on examples from the marine Upper Devonian in their sandstone classification schemes. Various aspects of the Upper Devonian fauna and flora have commanded the attention of paleontologists since early in the nineteenth century. In short, there is every reason to study these rocks not because of their attributes alone but added to that is their broad expanse of exposure both in the fold belt and in the Plateau and the enormous amount of well data available. The character, accessibility, diversity, and economic interest of these rocks work to command out attention.

Many uncertainties remain even with all of the attention. The stratigraphy is not yet firmly established over large areas and temporal relations are often obscure. The pattern of facies is known in broad outline but not in detail, especially in the subsurface. The biota remains largely unstudied, except at an uncritical taxonomic level, over much of the sequence. Notable exceptions exist of course (See: Oliver and Klapper, 1981) and much work is going on, but major questions remain.

SOURCE AREA

Sedimentary rocks of Paleozoic age occur at the surface or in the subsurface throughout the length of the eastern part of North America. Exposures of rock comprising the total sequence occur in the Appalachian Mountains and extend from central New York to Kentucky. The Cambrian and Ordovician rocks are dominantly carbonates although a moderate quantity of Lower Cambrian clastics occur. The source for these sediments appears to have been to the west. The remainder of the Paleozoic rocks are dominantly clastics and paleocurrent, isopach, and lithofacies data indicate derivation from an eastern source area.

The dramatic change from a western to an eastern source area and the apparent absence of an eastern source has only recently been satisfactorily resolved by the development of plate-tectonic models for the eastern margin of North America (Bird and Dewey, 1970; Schenk, 1971; Dietz, 1972; Hatcher, 1972; Dewey and Kidd, 1974; Rankin, 1975; and Van Houten, 1976). The general plate tectonic model for the eastern North American continental margin is shown in Figure 1.

During the Late Precambrian through the Early Ordovician the eastern margin of the North American continent was a miogeocline in which some clastics and much carbonate were deposited (Fig. 1B). Sediment entered the basin from the west. Sometime in the Ordovician, North American, South American, and African plate divergence stopped and convergence commenced. Convergence continued following the formation of an island arc system during the Ordovician (Fig. 1B), and a continental land mass, Appalachia, was developed by Middle Devonian time (Fig. 1E). Appalachia comprised uplifted and metamorphosed Precambrian(?), Cambrian, and Early Ordovician miogeoclinal sediments as well as volcanics and intrusives. This composition has been confirmed by identification of coarse clasts (Barrell, 1914; Mencher, 1939; Sevon, 1969; Perry and deWitt, 1977; Sevon and others, 1978; Seaman, 1979; and Kirby, 1981) and thin section petrography of finer-grained Catskill rocks (Mencher, 1939; Lucier, 1966; Sulenski, 1969; Kramers and Friedman, 1971; Humphreys and Friedman, 1975; and Sevon, unpublished data). These studies indicate a mixed terrain of low-grade metamorphic and sedimentary rocks and a general absence of feldspar. Quartzites are particularly common as coarse clasts, and sericite-chlorite-rich rock fragments are common in thin section.

Estimates of the position of Appalachia during the Devonian and Mississippian range from 40 km (Lucier, 1966) to 204 km (Pelletier, 1958) east of the present outcrop in Pennsylvania and New York. Its actual position is not known, but estimates of 50 to 100 km seem reasonable.

APPALACHIAN BASIN

After the development of Appalachia, the eastern part of North America became an elongate inland sea, the Appalachian basin, with a central focus of sediment accumulation in New York and Pennsylvania (Fig. 2; Colton, 1970; Cook and Bally, 1975) and farther east. The large quantities of sediment contributed by Appalachia caused marked subsidence in the eastern part of the basin, and presumably even greater thicknesses of Middle and Upper Devonian sediment, now lost to erosion, were deposited east of the present outcrop margin.

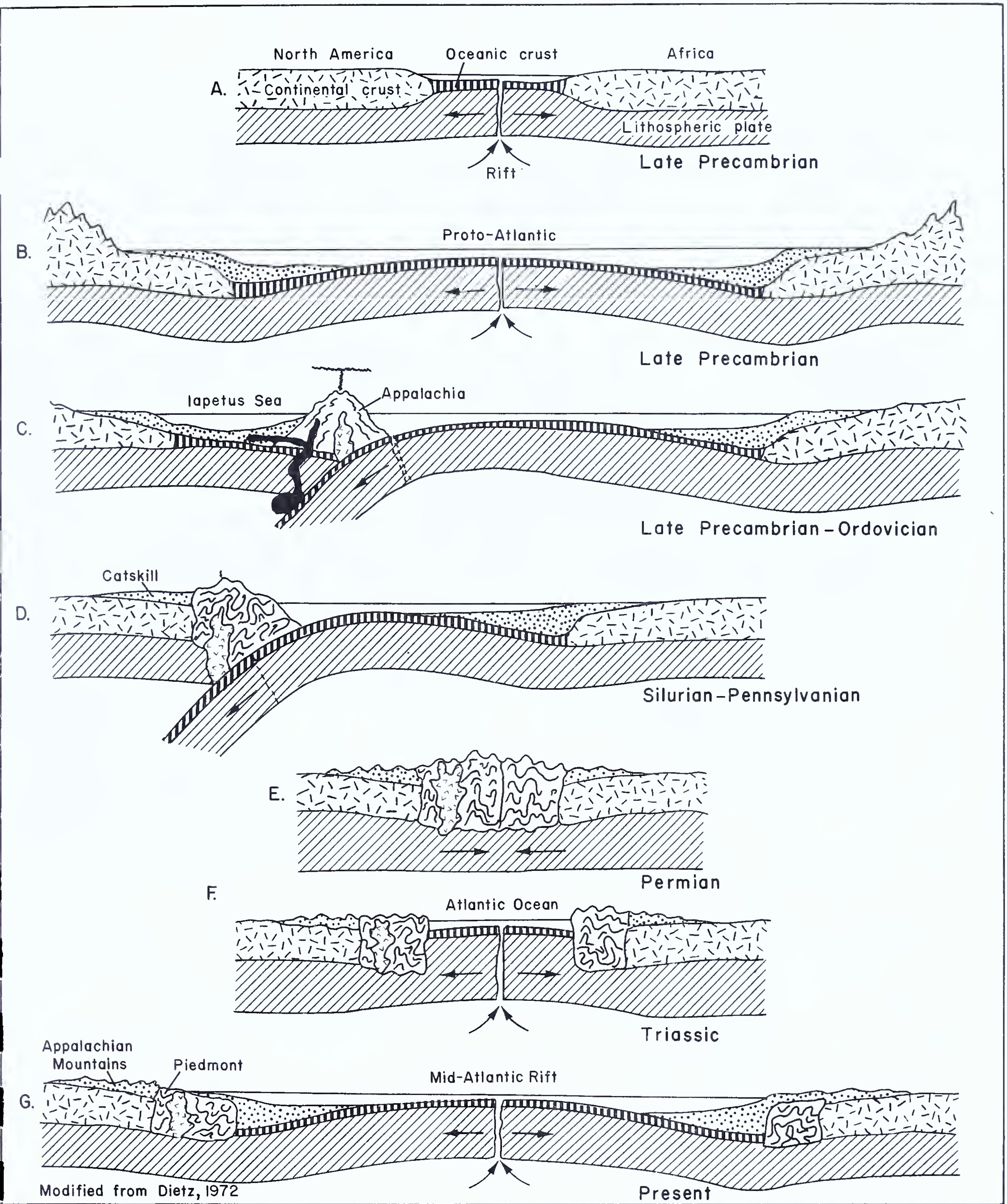


Figure 1. Diagrammatic model of the plate tectonic history of central Appalachian basin. Model modified from Dietz, 1972.

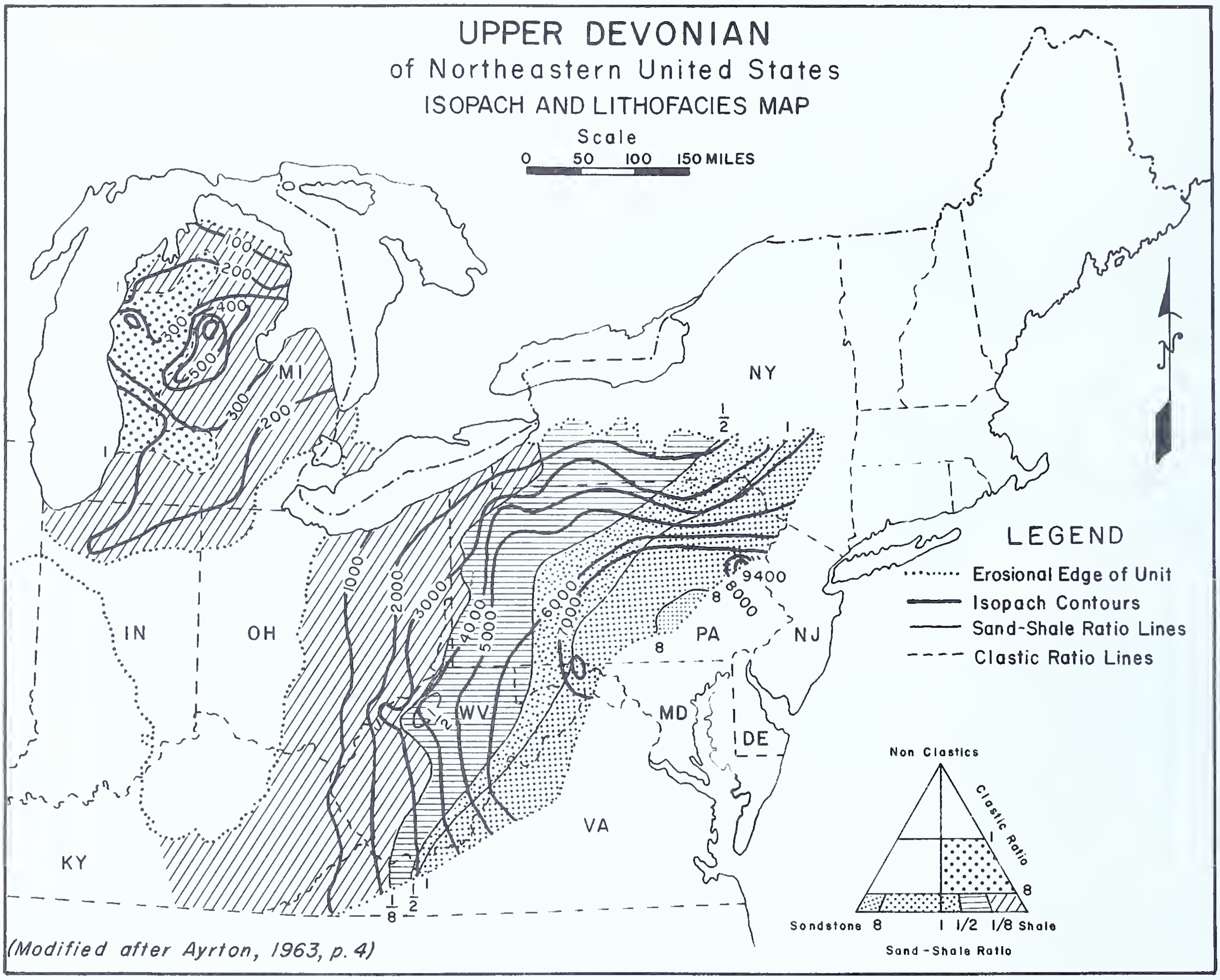


Figure 2. Isopach and lithofacies map for the Upper Devonian of northeastern United States.

Local tectonic activity contemporaneous with sedimentation in the Appalachian basin has been identified primarily in the present Appalachian Plateau part of the former depositional basin, but also occurred farther east. The presence of deep-seated faults along which recurrent movement occurred during Paleozoic sedimentation is discussed by Bradley and Pepper (1938), Woodward (1963), Kelley and others (1970), Harris (1975), Wagner (1976), and Root (unpublished, Pennsylvania Geological Survey, Harrisburg). Growth of folds and their effect on coal deposition in western Pennsylvania is discussed by Kent and Gomez (1971), Williams and Bragonier (1974), and McCulloch and others (1975). Growth of folds during Devonian sedimentation in eastern Pennsylvania and New York has been suggested by Fletcher (1964) and Fletcher and Woodrow (1970), and in northcentral Pennsylvania by Woodrow (1968b). The Wyoming-Lackawanna Basin in northeastern Pennsylvania was tectonically active during the Mississippian and may have been active during the Late Devonian (Woodrow and Fletcher, 1967; Glaeser, 1974).

PALEOGEOGRAPHY AND CLIMATE

Available paleoclimatic data combined with some paleomagnetic data allow reconstruction of Devonian world paleogeography (Woodrow and others, 1973; Heckel and Witzke, 1979; Ziegler and others, 1979; and Bambock and others, 1980) and a reconstruction for the Late Devonian is presented in Figure 3.

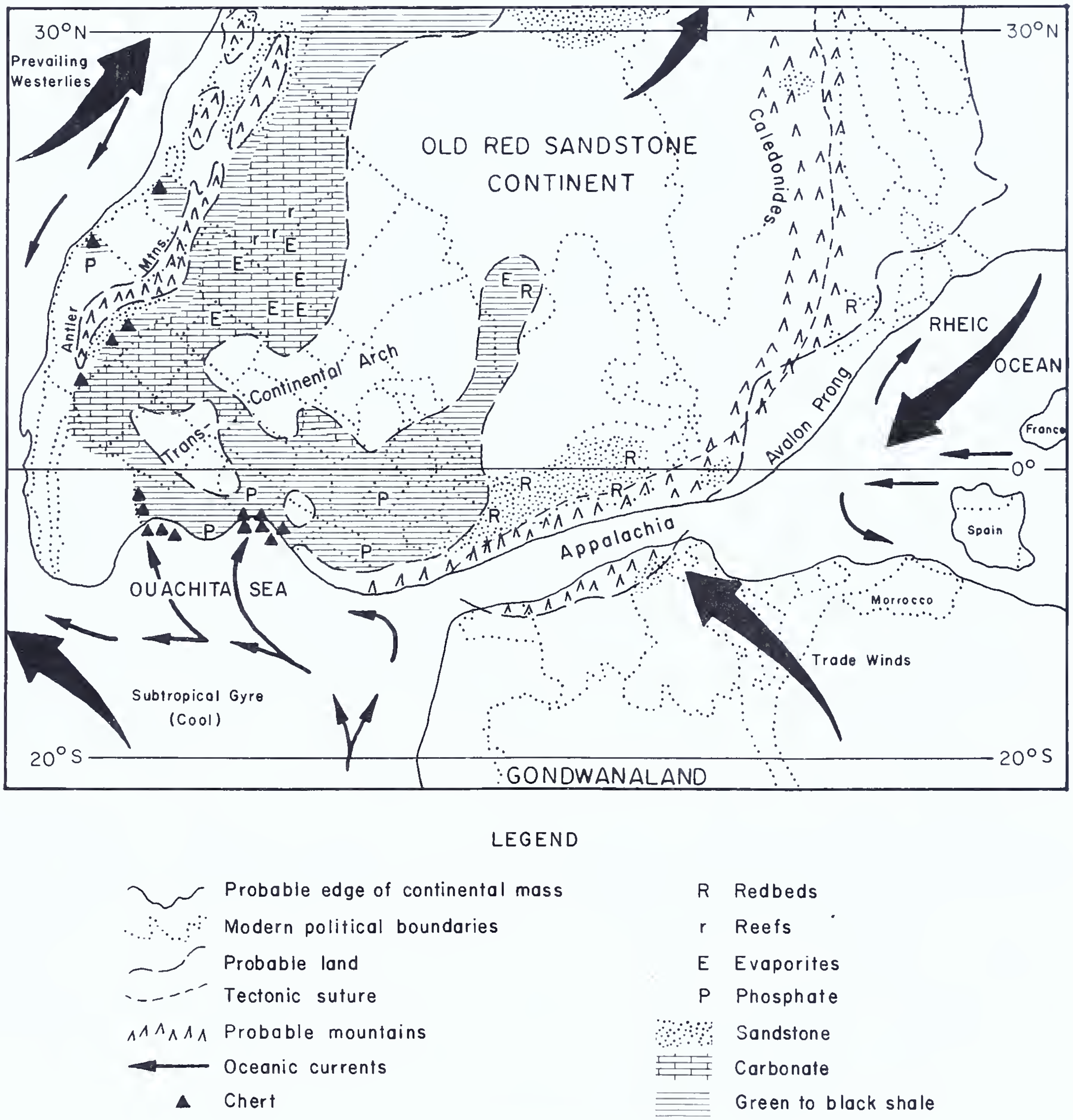


Figure 3. Late Devonian paleogeography and lithofacies for North America. Diagram simplified and modified from Ettensohn and Barron (1980, p. 18).

In this reconstruction, the Catskill deltaic system would have developed in an equatorial belt affected by easterly trade winds. Because of the wind barrier created by Appalachia, the Appalachian basin would have existed in a rain shadow and there is little evidence that winds played an important part in deposition within the basin. Seasonal aridity and warm-to-hot temperatures prevailed in the basin and presumably in the western part of Appalachia. Vegetation was sparse to lush on the depositional plain, but its seasonal fluctuations are not known. The extent to which vegetation may have existed in Appalachia is likewise not known.

MODERN ANALOG

The spatial and tectonic relationship between the New Guinea island arc and the Australian craton (Fig. 4) may be the modern analog for Appalachia

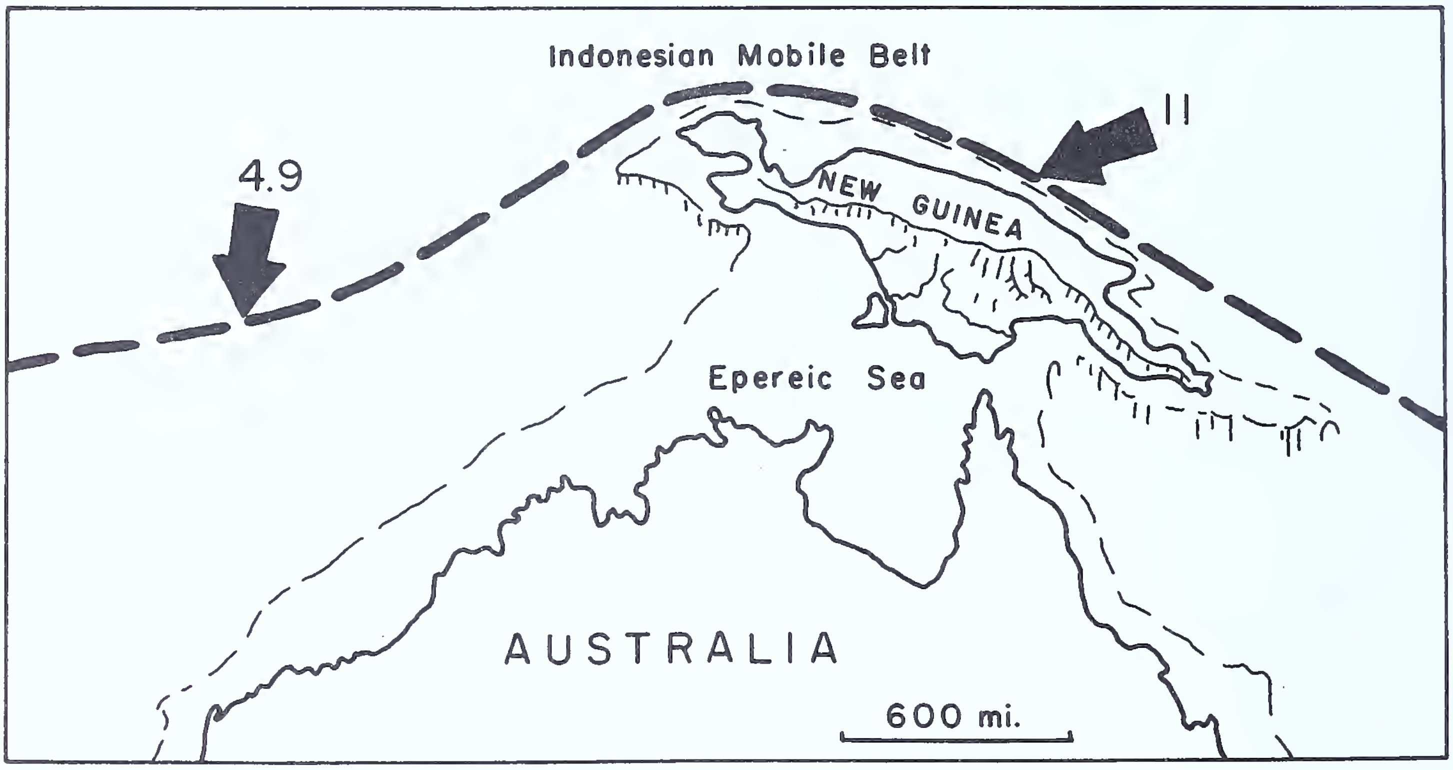


Figure 4. New Guinea and Australia - a modern analog for Appalachia and the North American craton (Dott and Batten, 1971, p. 295). Direction of tectonic compression indicated by arrows and rates given in cm/year (LePichon, 1968).

and the North American craton during part of the Paleozoic (Dott and Batten, 1971, p. 295). This situation lacks the potential continental collision from the northeast and development of a continental landmass, but otherwise seems to be a reasonable analog. The equatorial position is not the same in this model as during the Upper Devonian, but wind circulation appears comparable and climatic conditions may be similar.

DELTAIC SYSTEM

Introduction

Sediments deposited in the Appalachian basin during the Upper Devonian are often attributed to the "Catskill delta" with the implication that a single delta of unspecified nature was responsible for all of the sediments. The real situation was well stated by Barrell in 1913 (p. 466):

> "The uniformity in character of the delta from northeast to southwest, its development marginal to the uplands, and somewhat rapid gradation from gravel to sand and clay on leaving the mountains suggests the presence of a number of comparatively short streams which build flat coalescing fans rather than the debouchement of one or two great continental rivers."

Elaboration of this concept of Barrell follows.

Sediment-Input Systems

Willard (1934) was the first to attempt to define the number and position of the rivers which brought sediment to the Appalachian basin. He named and sited 3 delta lobes in Pennsylvania: Fulton (south-central), Snyder (central), and Wyoming (northeast). These lobes defined the hypothetical position of the early Chemung shoreline (the base of Chemung is marked by the first appearance of the brachiopod Cyrtospirifer "disjunctus"). Caster (1938) illustrated the position of 3 arcuate deltas in northwestern Pennsylvania, but says nothing about them. Sevon recently identified the position of the axes of 8 sediment-input systems for the Upper Devonian Appalachian basin (Fig. 5) (Sevon and others, 1978; Sevon, 1979a). Locations of axes of sediment-input systems in New York are given by Burtner (1964) and McCave (1968), and in Virginia-West Virginia by Dennison (1970) and Dennison and deWitt (1972).

Facies Progradation

At any particular instant of time during development of the Catskill clastic wedge, a variety of specific subaqueous and subaerial environments of deposition coexisted. As progradation and subsidence occurred, one depositional environment was succeeded by another and the resulting vertical sequence of sediments exemplified Walther's (1884) law of facies: under the controls of transgression or regression, facies which coexisted laterally will be preserved vertically in stratigraphic sequence. Generally the succession of environments was an orderly progression from farthest offshore to farthest onshore and the vertical sequence preserved today is, as a whole, one of upward coarsening. These lateral and vertical relationships are shown in Figure 6.

Although an orderly progression of rocks representing successive depositional environments occurs uninterrupted in some places, interruptions of orderly progression are common and represented by repetitive sequences. Documented examples of such sequences are: (1) the Irish Valley "motifs" (repeated facies sequences) in the Irish Valley Member of the Catskill

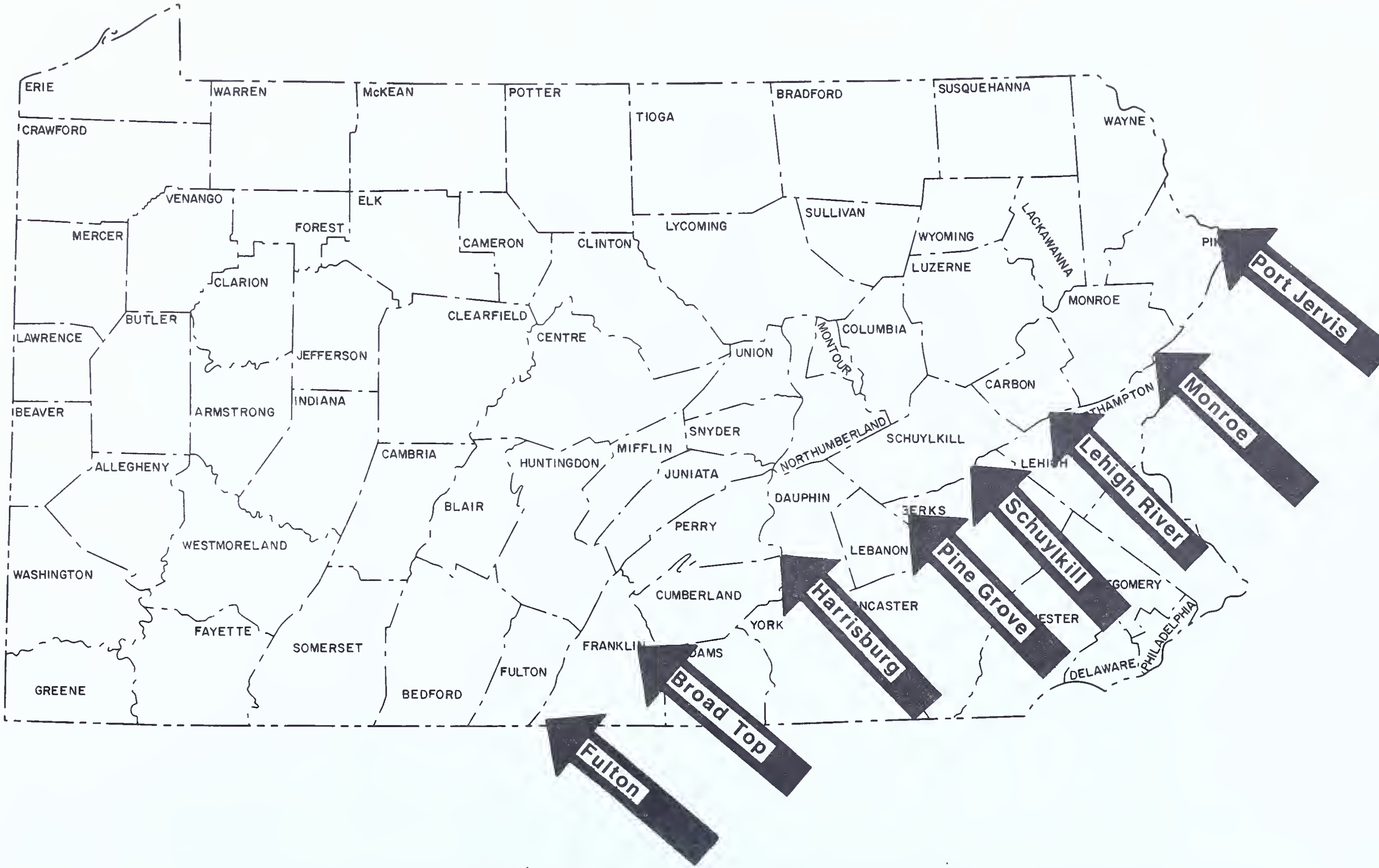


Figure 5. Interpreted centers of sediment-input systems entering the central Appalachian basin during the Devonian.

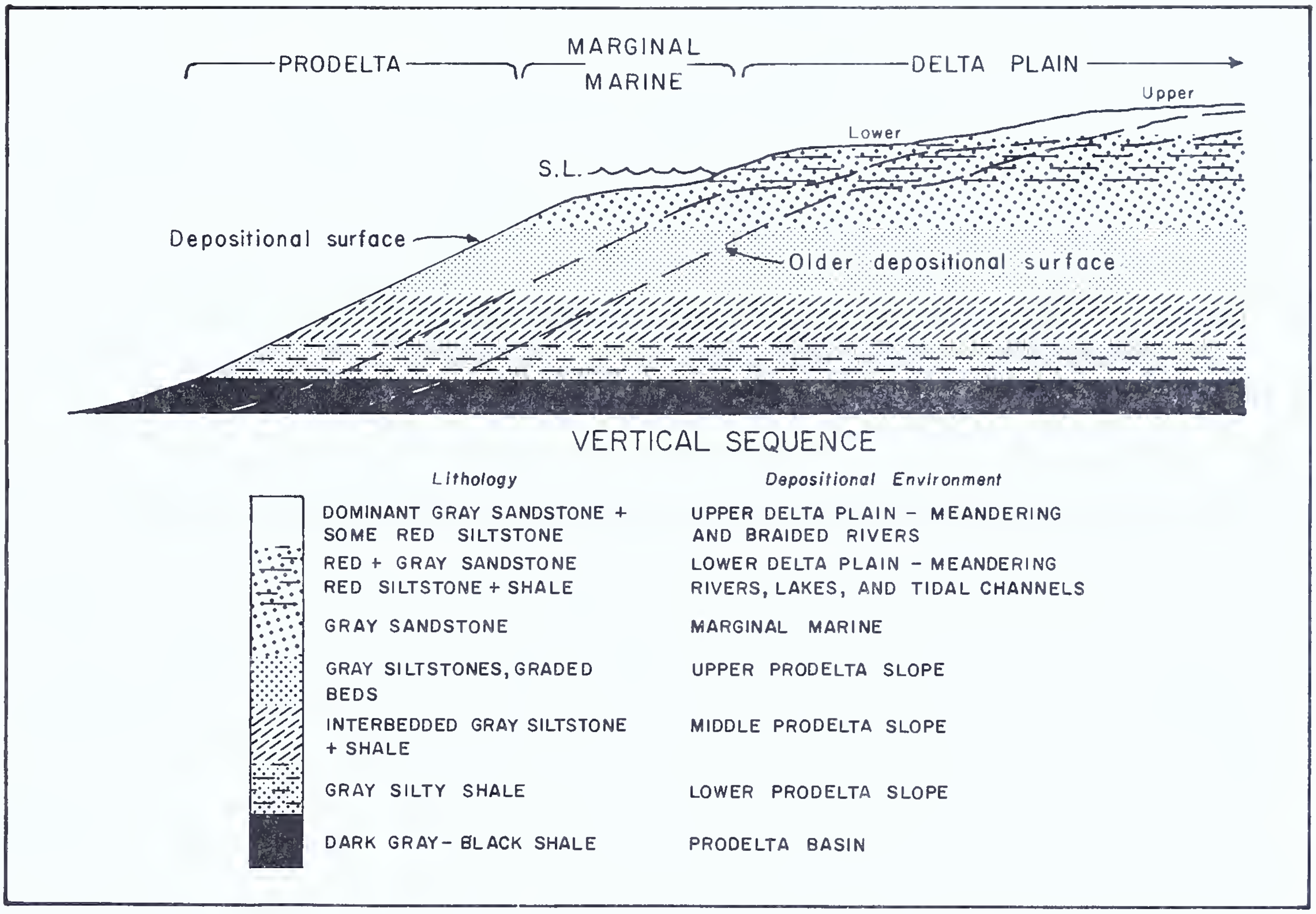


Figure 6. Idealized Middle and Upper Devonian Catskill delta progradation model. Modified from Glaeser (1979, p. 347).

Formation, east central Pennsylvania (Walker and Harms, 1971; Walker, 1972); (2) The Walcksville, Beaverdam Run, and Long Run Members of the Catskill Formation in northeastern Pennsylvania (Epstein and others, 1974; Berg, 1975; Berg and others, 1977); (3) Changes in depositional environment and resulting rocks are correlated with major basin-wide sea level variations by Sutton (1963), Sutton and others (1970), and Dennison and Head (1975); (4) Ettensohn and Barron (1981) present a model for the cyclic alternation of black shales and coarser clastics in the Catskill clastic wedge; and (5) Glaeser (1974) recognized both regular environmental succession and numerous interruptions in sequence in rocks of the Catskill Formation preserved in the subsurface of northeastern Pennsylvania.

Delta Model

Although the term delta has been applied many times to the origin of the progradational deposits of the Catskill delta, a specific model has never been established. In fact, both Allen and Friend (1968) and Walker and Harms (1971) rejected the concept of deltaic deposition. Allen and Friend suggested that Catskill sedimentation occurred in a vast alluvial coastal plain characterized by barrier islands, tidal flats, and lagoons at its western margin, and by meandering and braided streams in its eastern parts. Walker and Harms argued that, at least in south central Pennsylvania, deposition occurred along

a quiet, muddy, prograding coastline which received sediment via longshore currents from a distant source.

In reality, however, the overall progradational character of the Middle and Upper Devonian rocks is consistent with the definition of a delta given by Ferm (1970, p. 247-248):

> "Recent marine deltas form when sediments, carried by rivers into relatively large bodies of open water, accumulate at the river mouth until the surface of the sediment pile reaches sea level. The emergent portion comprises the subaerial expression of the delta . . . Delta growth continues as sediment-laden streams pass over the emergent surfaces and deposit sand, silt, and clay over the frontal delta slope. As this process of building new land at the delta margin continues, the delta is said to prograde, and the product of progradation can be thought of as the typical delta sequence."

The formation of the Catskill clastic wedge fits this definition of a delta, but no single delta model can be applied to the whole because the numerous sediment-input systems varied in several ways which affected the manner in which each interfaced with the Appalachian basin:

1. The intensity and timing of orogeny was laterally variable resulting in differential uplift in Appalachia and differential sediment supply to the basin.

2. The length of each of the numerous sediment-input rivers varied through time in relation to itself and the other rivers. This variation resulted in differences in gradient, grain size of the sediment transported, and, possibly, sediment quantity. These differences in turn caused variations in the character of the depositional environments associated with each stream.

3. The interaction between adjacent sediment-input systems was variable.

The result of the large potential for variation during deposition of the Catskill clastic wedge is that the rocks comprising that wedge are extremely variable in both the vertical and horizontal dimensions. Thus, the interpretations of both Allen and Friend (1968) and Walker and Harms (1971) are correct for specific rocks in specific places, but those interpretations do not necessarily apply to other rocks in other places.

Friedman and Johnson (1966) pointed out that the Catskill deltaic complex in New York state differs considerably from the modern Mississippi River delta (a frequently used model at that time), but is deltaic in nature. Manspeizer (1969) outlined the physical character and dimensions of a single delta complex in south-central New York and north-central Pennsylvania, but, unfortunately, he did not apply a specific model to the rocks nor did he publish the details of the study. The only satisfactory fitting of a delta model to Devonian rocks in Pennsylvania is the work of Kaiser (1972) who establsihed the suitability of the Rhone River delta model for the Middle Devonian Montebello Member of the Mahantango Formation in south-central Pennsylvania. Much work remains to be done before even a general model of the

whole progradational complex can be generated.

Depositional Environments

Upper Devonian rocks in New York and Pennsylvania have long been attributed to sediment deposition in both marine and non-marine environments. However, it has only been in the last 25 years that specific depositional environments have been recognized and described in detail for these rocks. Table 1 presents a summary of the various environments which have been described. There is adequate literature available describing the characteristics of these environments and they are not elaborated upon here. Figure 6 illustrates the lateral and vertical position of the broad categories in which more specific environments occur.

Progradation of the Catskill clastic wedge across Pennsylvania was accompanied by two important changes: (1) a continuing increase in distance of the shoreline from the source area, and (2) a decrease in gradient of the fluvial component. These changes resulted in a southeast to northwest (the general trend normal to depositional strike) decrease in maximum clast size and an increase in complexity of depositional environments. Another result of these changes was that the location of the centers of sediment-input systems, which have been defined along the southeastern margin of Upper Devonian outcrop (Fig. 5), are difficult to assess farther to the northwest. Insufficient sedimentological work has been done as yet to ascertain whether these discrete sediment-input systems retained their integrity across the depositional basin or whether some systems coalesced to form fewer, larger systems. Rahmanian (1979) identified the position of one system in Centre County, but the location of no other systems have been identified at such a distance from the source area.

As progradation of the Catskill delta system progressed across Pennsylvania, the shoreline at any particular time was probably very irregular and was controlled by a balance between rate of sediment supply, rate of subsidence, position of different sediment-input systems, and oceanic processes. Passing from the shore seaward, sedimentary facies built on this surface were those of (1) the nearshore (Stops 1, 3, and 11), a complicated patchwork of facies reflecting the environments where the effects of the river input, tides, and waves were felt, (2) the inner clinoform (Stop 2), a simpler facies plan of delta platform, interdistributary bays, transgressive beaches, and others, (3) the outer clinoform (Stop 10), with delta-front, prodelta, proximal turbidite, and open shelf facies, and (4) the basin, with its distal turbidites and pelagic sediments. As these facies were pushed northwestward by the continuing supply of sediment, the emergent part of the clastic wedge was built mainly by fluvial deposition. Meandering stream facies (Stop 5), with channel and overbank sediment combining to form characteristic fining-upward cycles, dominated the fluvial deposition. Braided stream facies comprised a small part of the clastics and were restricted mainly to the centers of sediment-input systems. Lake deposits in small depressions and meander cut-offs (Stop 5) formed a minor, and as yet relatively unknown, part of the depositional scene.

By the time progradation reached Tioga and Bradford Counties, sediment-bearing streams were extended more than twice as far from the source area than they were along the present southeast margin of Upper Devonian outcrop.

Table 1. Environments of deposition identified in Middle and Upper Devonian rocks of New York and Pennsylvania.

Environment Source	Geographic Area	Rock Unit
Alluvial fan		
Sulenski, 1969	GPO*	Skunnemunk Fm.
Kirby, 1981	GPO	Skunnemunk Fm.
Braided rivers		
Lucier, 1966	SE NY	Kiskatom-Kaaterskill Fms.
Buttner, 1968	SE NY	Genesee Gp.
Friedman, 1972	SE NY	Catskill Fm.
Glaeser, 1974	NE PA	Sawmill Run
Epstein & others, 1974	NE PA	Berry Run-Clarks Ferry Mbrs.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Buttner, 1977	SE NY	Genesee Gp.
Sevon & others, 1978	NE PA	Duncannon Mbr.
Rahmanian, 1979	C PA	Duncannon Mbr.
Kirby, 1981	GPO	Skunnemunk Fm.
Meandering rivers		
Allen, 1965	NE PA	Catskill Fm.
Woodrow & Fletcher, 1967	SE NY-NE PA	Catskill Fm.
McCave, 1968	SE NY	Moscow-Ludlowville Fm.
Johnson & Friedman, 1969	SE NY	Tully Fm.
McCave, 1969	SE NY	Catskill Fm.
Sulenski, 1969	GPO	Bellvale Fm.
Friedman, 1972	SE NY	Catskill Fm.
Glaeser, 1974	NE PA	Duncannon Mbr.
Epstein & others, 1974	NE PA	Duncannon Mbr.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Buttner, 1977	SE NY	Catskill Fm.
Rahmanian, 1979	C PA	Sherman Creek Mbr.
Dune		
Johnson & Friedman, 1969	SE NY	Tully Fm.
Delta plain		
Glaeser, 1974	NE PA	Walcksville-Long Run Mbrs.
Epstein & others, 1974	NE PA	Walcksville-Long Run Mbrs.
Kirby, 1981	GPO	Bellvale Fm.
Marsh		
Sutton & others, 1970	SC NY	Sonyea Fm.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Interdistributary bay		
McCave, 1968	SE PA	Moscow-Ludlowville Fm.
Tidal deposits		
Woodrow & Fletcher, 1967	SE NY-NE PA	Catskill Fm. (PA) and Laurens and Manorkill Fm. (NY)
McCave, 1968	SE NY	Moscow-Ludlowville Fm.
Johnson & Friedman, 1969	SE NY	Tully Fm.
Friedman, 1972	SE NY	Tully Fm.
Humphreys & Friedman, 1975	NC PA	Catskill Fm.
Rahmanian, 1979	C PA	Irish Valley Mbr.

Table 1. (Continued)

Environment Source	Geographic Area	Rock Unit
Distributary mouth bars		
Sulenski, 1969	GPO	Bellvale Fm.
Sutton & others, 1970	SC NY	Sonyea Fm.
Krajewski & Williams, 1971	NE PA	Catskill Fm.
Epstein & others, 1974	NE PA	Towamensing Mbr.
Berg, 1977	GPO	Bellvale Fm. (upper)
Kirby, 1981	GPO	Bellvale Fm.
Tidal channels		
Sutton & others, 1970	SC NY	Sonyea Fm.
Kirby, 1981	GPO	Bellvale Fm.
Estuaries		
Sutton & others, 1970	SC NY	Sonyea Fm.
Beach		
Lucier, 1966	SE NY	Kiskatom-Kaaterskill Fms.
Krajewski & Williams, 1971	NE PA	Catskill Fm.
Delta front		
Glaeser, 1974	NE PA	Towamensing Mbr.
Delta platform		
Sutton & others, 1970	SC NY	Sonyea Fm.
Nearshore shallow marine		
McCave, 1968	SE NY	Moscow-Ludlowville Fm.
Offshore bar		
Johnson & Friedman, 1969	SE NY	Tully Fm.
Krajewski & Williams, 1971	NE PA	Catskill Fm.
Distal bar		
Kirby, 1981	GPO	Bellvale Fm.
Lagoon		
Lucier, 1966	SE NY	Kiskatom-Kaaterskill Fms.
Johnson & Friedman, 1969	SE NY	Tully Fm.
Friedman, 1972	SE NY	Hamilton Gp.
Prodelta		
Sulenski, 1969	GPO	Bellvale Fm.
Sutton & others, 1970	SC NY	Sonyea Fm.
Glaeser, 1974	NE PA	Trimmers Rock Fm.
Epstein & others, 1974	NE PA	Trimmers Rock Fm.
Slope shales		
Walker, 1972	SC PA	Irish Valley Mbr.
Open shelf		
McCave, 1968	SE NY	Moscow-Ludlowville Fm.
Sutton & others, 1970	SC NY	Sonyea Fm.

*GPO = Green Pond Outlier

Stream gradients were low, transported sediments were fine-grained, and tidal range in the area was apparently less than 2 m. The sedimentological results of these factors, as reflected in the rocks now exposed, are an extensive planarity and uniformity of discrete beds and abrupt vertical changes in depositional environments. Deposition on the emergent part of the clastic wedge was by sluggish meandering streams loaded with fine-grained sediment. Delta lobes and sublobes in the marginal marine area were involved in a delicate interplay between sediment influx, subsidence, and open sea processes. As one delta lobe actively prograded, an adjacent one, cut off from sediment supply, subsided through compaction and was transgressed by brackish or marine water. Eventually sufficient sediment accumulated to create a totally emergent delta plain and the shoreline moved farther northwest.

PALEONTOLOGY

The Appalachian basin had abundant life during the Middle and Upper Devonian. marine invertebrates flourished wherever appropriate environmental niches were available. Fish were apparently abundant in the rivers flowing from Appalachia and lungfish survived the dry seasons (aestivation) by burrowing into fluvial muds (Stop 5). A variety of air-breathing creatures left abundant tracks and trails in the alluvial muds. Land plants were at least seasonally abundant on the delta plain, but their presence or absence in Appalachia is conjecture.

The fossil remnants and fossil traces of the various forms of life vary from abundant in rocks of marine origin (Stops 1, 2, 3, 10, 11) to absent in many rocks of non-marine origin. Good entries into the literature of the marine faunas associated with the clastic wedge are: McGhee and Sutton, 1981; Thayer, 1974; Bowen and others, 1974; Willard and others, 1939; and numerous papers in House and others, 1979. The distribution of trace fossils in the Catskill in New York was recently reviewed by Miller (1979). Berg (1973, 1977) discusses bivalve burrow structures, and Woodrow (1968a) documents aestivation burrows of Devonian lungfish. The world of Devonian plants can be entered through papers by Banks (1966) and Chaloner and Sheerin (1979).

STRATIGRAPHY

Many of the Upper Devonian rock units recognized in Bradford and Tioga Counties were originally treated as extensions of rock units earlier defined in New York (Willard and others, 1939). The reasons for this approach are: (1) the obvious comparability of the rocks and the fossils involved, and (2) the proximity of the New York sections to those under discussion. The primary basis of correlation then was the gross aspect of physical stratigraphy with a little help from the fossils. No attention was paid to key beds. Such an approach is not without risk of error as the distance from the type section becomes more than a few tens of kilometers. This is especially true in a deltaic sequence where facies change is the norm, where distinctive rock types may be repeated through hundreds of meters of vertical sequence, where most rock units are diachronous, and where exposures are small and widely spaced. Of course, concern about the problems raised by facies change and diachronous units does not occur if the intention is to map rock units without putting them into a temporal framework. However, to do so may hide the subtleties

of the subdued geologic structure found in this part of the Appalachian Plateau and it will make interpretation of the areal distribution of environments at any point in delta development very difficult, and, ultimately, it will make interpretations of paleogeography nearly impossible.

In the decades since Willard's work, increased attention has been paid to key beds in the New york Devonian and the increased availability of sample logs from exploratory wells has made it possible to more accurately trace rock units into this region from their New York type sections on the basis of key beds (Woodrow, 1968). Recently, preliminary results from the Eastern Gas Shales Project have made clear the physical stratigraphy of the basinal Devonian rocks of the Appalachians (Roen, 1980; West, 1978; Roen and others, 1978). This work is based on tracing key, black shales in the subsurface using sample and gamma-ray logs. Black shale units have been traced from New York, Ohio, and Kentucky into West Virginia and Pennsylvania. Extension of these units into the non-marine successions is complete in New York and partly advanced elsewhere. It is these extensions into the transitional sequences of Bradford and Tioga Counties which form the basis of the stratigraphic units noted by Woodrow and shown in the Frontispiece. Recent detailed mapping of the Lock Haven Formation marine succession and overlying Catskill strata in the Lycoming County and Columbia County areas has revealed no key black or dark gray shale beds which may be used in stratigraphic subdivision.

Connection of the rock unit (physical) stratigraphy with time-stratigraphic units has long been a feature of the New York Devonian (Rickard, 1975; Oliver and Klapper, 1981). With the New York section as a base, the physical and time-stratigraphy in Bradford and Tioga Counties seem secure. Extending this connection to other basinal facies is well advanced in West Virginia and elsewhere along the Appalachian trend based on biostratigraphy (Duffield and Warshauer, 1981) and on tephrostratigraphy (Collins, 1979).

Additional mention must be made about two major rock subdivisions recognized early by the New York Geologic Survey which later became facies designations: Chemung and Portage. Both terms were applied widely in the Appalachians and often incorrectly. The Chemung was recognized as a shelly, fine-grained sandstone and shale unit which everywhere overlaid the sparsely fossiliferous, very fine grained sandstone, siltstone, and dark gray shales of the Portage. The history of these terms is very complicated and is not important here, but with the work of G. Arthur Cooper, George Chadwick, and Bradford Willard (among others) in the 1920's and 1930's, the rock units, facies and temporal relations became clear. Caster (1934) and Willard and others (1939) put the facies and rock units into perspective for northern Pennsylvania and southern New York and in doing so provided us with facies terminology still useful today (Rickard, 1975).

In contrast to stratigraphic practice in New York State, the Pennsylvania Geological Survey has traditionally mapped rock-stratigraphic units and has thus developed a different stratigraphic framework. These map units represent, for the most part, reasonably homogenous lithologic entities with more or less distinct boundaries. Although genesis is not considered a part of the definition of a rock-stratigraphic unit, it controls the composition of rock sequences and the uniformity or diversity of their lithologic components. Thus, the orderly progression of progradational lithologies shown in Figure

6 can be easily subdivided into mappable rock-stratigraphic units in part, but not completely.

Those rocks which originated in the prodelta basin and prodelta environments are generally relatively uniform in lithology and comprise good map units although their boundaries are frequently transitional.

Rocks which originated in subaerial depositional environments are characterized by a diversity of lithologies created by (1) multiple depocenters, (2) multiple depositional environments, and (3) variable distance from the source area. This diversity complicates rock-stratigraphic subdivision for these rocks. As a result, the approach in Pennsylvania has been to map assemblages of heterogeneous rocks which generally have arbitrary boundaries. These subdivisions may be well-defined in one area (e.g., Carbon County, PA; Epstein and others, 1974), but lack lateral persistence and require redefinition [e.g., Poplar Gap Member of the Catskill (Berg, 1975)]. In general, useful subdivisions of the Catskill Formation have been erected wherever detailed mapping (scale 1:24,000) has been done and the lateral relationships of these subdivisions has been established. The Frontispiece presents the Upper Devonian stratigraphy currently used in north-central Pennsylvania.

Application of the term Lock Haven Formation in the Tioga and Bradford Counties area is somewhat problematical. Proper use of the term Lock Haven Formation requires recognition of the underlying Brallier Formation. Because an inadequate thickness of rocks below the base of the Catskill Formation is exposed in north-central Pennsylvania to bring Brallier or Brallier-equivalent rocks to the surface (see Piotrowski and Krajewski, 1977), the base of the sequence called Lock Haven is not exposed. However, (1) the presence of the Brallier to the south in the Williamsport area, (2) the fact that Tioga and Bradford Counties are thought to have been equally as far from the source area at the time of deposition, and (3) the lithologic similarity to rocks identified as Lock Haven elsewhere are the basis for application of the name in the Field Conference area.

HUNTLEY MOUNTAIN FORMATION

by
T. M. Berg

When the new state geologic map of Pennsylvania was being compiled, it was recognized that the term "Pocono" had been widely applied for many years over the north-central part of the state in a time-stratigraphic sense (Berg, 1979). The Catskill Formation had been mapped as a proper rock-stratigraphic unit. The rock sequence between the top of the Catskill and the presumed Devonian-Mississippian systemic boundary was referred to as the "Oswayo" Formation following the usage of Glenn (1903), Fuller and Alden (1903a and b), and Willard and others (1939). The succession between the Devonian-Mississippian boundary and the redbeds of the Mauch Chunk Formation were called "Pocono". Where the Mauch Chunk is missing due to pre-Pennsylvanian erosion, "Pocono" was applied to all remaining strata considered to be Mississippian. The name was carried into the marine clastic sequence of western Pennsylvania and applied to all rocks between the Devonian-Mississippian boundary and the unconformity at the base of the Pennsylvanian Pottsville Group. The wide application of the term "Pocono" in a time-stratigraphic sense is discussed in greater detail by Berg and Edmunds (1979).

The Burgoon Sandstone of the Allegheny Plateau is considered the lithostratigraphic equivalent of the Pocono Formation (Glaeser, 1973; Berg, 1979). For the 1980 state geologic map, the term "Pocono" was pulled back from its wide application as a time-stratigraphic unit and limited to the anthracite regions, and to the region around the Broad Top coal field. Pocono and Burgoon are shown as the same color on the 1980 state map. For many years, the Burgoon Sandstone was included as an uppermost subdivision of the "Pocono" of the Plateau. The Burgoon Sandstone was mapped as a separate stratigraphic unit for the 1980 state map, and the sub-Burgoon "Pocono" plus the former "Oswayo" were given the new name "Huntley Mountain Formation" (Berg and Edmunds, 1979).

In north-central Pennsylvania, including the area of this Field Conference, there is no clear upper lithic break that can be used to perpetuate the term "Oswayo." As was mentioned above, that term had been extended widely in a partly time-Stratigraphic sense. The new Huntley Mountain Formation includes the transitional succession between the Catskill Formation and the Burgoon Sandstone. The Huntley Mountain spans the Devonian-Mississippian systemic boundary.

The Huntley Mountain Formation comprises greenish-gray to light-olive-gray sandstones, and some thin beds of grayish-red siltstone or shale. This nonmarine succession consists of a 200-m-(650-ft-) thick transition in which the lower sandstones are similar to gray sandstones of the subjacent Catskill Formation, and the upper sandstones are similar to the overlying Burgoon sandstones. Colton (1963, 1968) and Colton and Luft (1965) mapped this transition as a pair of unnamed, informal stratigraphic units in the Cedar Run, Waterville, and Slate Run quadrangles. The division between Colton's two informal units was based on a medial conglomerate bed called the "conglomerate at Cedar Run." His "lower sandstone sequence" and "upper sandstone sequence" were lumped together for the 1980 state map, and named

the Huntley Mountain Formation. The type section is at Huntley Mountain, just north of town of Waterville, Pennsylvania, in Lycoming County. Because the "conglomerate at Cedar Run" is not everywhere present over the entire extent of the Catskill-to-Burgoon transition, the new formation was not divided into formal members.

Sandstones of the Huntley Mountain are trough crossbedded or planar bedded, and frequently display linguoid or sinuous ripple marks or parting-step lineation. Sets of cross strata in the Huntley Mountain are generally less than 0.5 m (1.6 ft) thick, and are broad and gently shaped, in contrast with the higher angle, more strongly developed trough crossbedding of the Burgoon Sandstone. Disintegration of the fairly common planar bedded unit, produces abundant flaggy float on steep slopes. Most of the Huntley Mountain sandstones are immature phyllarenite or immature subphyllarenite. Burgoon sandstones fall into the subphyllarenite category. Analyses of Catskill sandstones are closely similar to Huntley Mountain sandstones. Huntley Mountain and Catskill sandstones are predominantly fine grained; Burgoon sandstones are predominantly medium grained.

The red shale or siltstone units within the Huntley Mountain Formation comprise approximately 5 percent of the total formation. These red beds are most commonly located at the tops of fining-upward fluvial cycles. Locally the red beds grade upward to thin gray and greenish-gray shale or siltstone.

Other minor components in the Huntley Mountain include intraformational conglomerate ("shale-chip breccias"), extraformational conglomerate (local quartz granule zones; "conglomerate at Cedar Run"), and calcareous pisolith beds (see Stop 6 in this guidebook).

The lithologies and textures of the Huntley Mountain Formation occur as phases arranged in fining upward fluvial cycles (Stop 4). The cycles typically break down into two basic subdivisions as defined by Allen (1965): a lower coarse member and an upper fine member. Coarse-member phases include conglomerate (intraformational or extraformational), medium-scale cross-stratified sandstone, planar-bedded sandstone, and small-scale cross-stratified or ripple-bedded sandstone. Fine-member phases include small-scale cross-stratified or ripple-bedded siltstone (sometimes having very thin sandstone interbeds), shale beds, and claystone. Upper fine-member sediments may be red, nonred, or a combination of both. Not every cycle bears every phase. For example, the intraformational-conglomerate phase generally occurs at the base of a cycle, but many cycles lack well-developed intraformational conglomerate. The uppermost shale and claystone phase of a cycle may be absent. All cycles have at least some of the phases of the lower coarse member and the upper fine member. In most cycles, the upper fine member is quite thin (less than 1 m) and may be represented only by ripple-bedded nonred silt shale. The lower coarse member is normally the thickest part of a cycle. Some repetitions or subcycles in the major cycles exist. For example, a thin lens of intraformational conglomerate may appear as a minor break in a cross-stratified sandstone sequence, well above the main basal disconformity. Alternations of planar-bedded and cross-stratified sandstone are repetitions of two phases within the lower coarse member of a cycle. Repetition of siltstone grading up through shale to claystone may occur several times as nested subcycles within the upper fine member of a cycle.

The Huntley Mountain Formation weathers to a series of small cliffs or very steep slopes, separated by benches or very gentle slopes. The cliffs or steep slopes are underlain by the resistant sandstones, and the benches are underlain by redbeds or nonred fine clastics. This geomorphic expression gives the impression of an intricate staircase or a wedding cake, and is easy to recognize on aerial photographs. The presence of lines of springs located at the red-bed horizons also gives a horizontally striped vegetation pattern on the aerial photographs. The overlying Burgoon Sandstone has a very distinctive, thick, massive form on aerial photographs, and is generally very easy to identify. It is commonly expressed as a pair of cliff-forming units that stand out boldly in contrast to the smaller cliffs and ledges of the Huntley Mountain Formation. No outcrop of the Burgoon is included as a stop on this Field Conference, but we will be passing over Burgoon terrain on Barclay Mountain on Day 1, and as we ascend East Hill from Drapes on our way to Stop 8 (Day 2). In most places, the underlying Catskill Formation displays a gentler and more rolling topography than does the overlying Huntley Mountain. This expression is due to the greater proportion of red shales and siltstones in the Catskill. Where there are a greater-than-average number of sandstones in the upper Catskill, it is difficult, if not impossible, to distinguish Huntley Mountain from Catskill solely on the basis of photographic interpretation.

The upper limit of the Catskill Formation as used in north-central Pennsylvania follows the usage of Colton (1968), who mapped the top of his "redbed sequence" as the highest occurrence of grayish-red sandstone. This is the most useful criterion for locating the base of the Huntley Mountain Formation. Additionally, the Huntley Mountain has a greater proportion of sandstone than the Catskill, and the geomorphic expression of the Huntley Mountain tends to bear this out. Where there is difficulty in separating Catskill from Huntley Mountain, the sandstone color becomes a very important criterion for differentiation. Huntley Mountain sandstones are more strikingly greenish gray and light olive gray, whereas Catskill sandstones are normally medium dark gray with some greenish-gray cast, grayish red, and brownish gray. Locally, brownish-gray, very fine grained sandstone may be found in the Huntley Mountain Formation, but no grayish-red sandstone has been observed.

The Burgoon Sandstone is characterized by medium-grained, buff, strongly trough crossbedded sandstone, having no red-bed components. There are no fining-upward fluvial cycles present in the Burgoon. Greenish gray and light olive gray are not typical Burgoon colors. The Burgoon is commonly conglomeratic near the base, having quartz pebbles that average less than 1 cm (0.4 in.) in diameter. In many places, this conglomeratic sandstone rests directly on the "Patton" red reds of the Huntley Mountain and forms a clear-cut and easily mappable contact. Where the "Patton" is missing, it is still fairly easy to distinguish the fine-grained, light-olive-gray, flaggy, thin-bedded sandstone of the Huntley Mountain Formation from the overlying Burgoon. Locally, the Huntley Mountain sandstones are medium grained, and do tend to have a buff appearance. In this case, observation of crossbedding style usually reveals that Huntley Mountain sandstones are much more gently crossbedded, and at a lower angle. Troughs in the Huntley Mountain do not have as great an amplitude as Burgoon Sandstone troughs. Planar bedding and platy or flaggy fragmentation are more typical of the Huntley Mountain. Slabby, rubbly, and block fragmentation are more typical of the Burgoon.

The Spechty Kopf Formation is the clastic sequence between the Catskill and Pocono Formations of eastern Pennsylvania. It is the approximate lateral equivalent of the Huntley Mountain Formation. Spechty Kopf sandstones are usually yellowish gray, olive gray, or brownish gray. The Spechty Kopf also includes polymictic diamictite of variable thickness and distribution at the base, grading up through pebbly mudstone to laminite (Sevon, 1979). The Spechty Kopf Formation is separated from the Huntley Mountain Formation at the Milton anticline, northwest of the Lackawanna syncline. This location is chosen partly because the Huntley Mountain-Spechty Kopf interval is missing by erosion, and the anticline forms a convenient natural break. The Huntley Mountain sandstones, as a general rule, are more greenish gray in contrast to the olive, yellowish, and buff colors of the Spechty Kopf. Minor red beds occur in the Spechty Kopf and do not serve as a criterion of distinction from the Huntley Mountain.

The term "Rockwell" of Maryland usage was carried into Pennsylvania for the 1980 state geologic map. The Rockwell Formation includes all the strata between the Catskill Formation (Hampshire Formation of Maryland) and the Burgoon Sandstone (Purslane Formation of Maryland). The Rockwell is the southern lateral equivalent of the Huntley Mountain and was traced from Maryland at least to the region north of Altoona. Rockwell Formation sandstones are medium light gray or light olive gray to buff. Some thin red shales and greenish shales have been recorded along with brown shales, greenish-gray and gray sandstones, red variegated shales, and a greenish-black or bluish-black shale containing marine fossils in the sub-Burgoon sequence above the Catskill Formation in the Broad Top basin of south-central Pennsylvania. Sevon (1979) has documented the occurrence of polymictic diamictite in the lower Rockwell Formation in eastern Bedford County. The Rockwell therefore includes a greater variety of lithologies, notably a marine shale and a diamictite, and also some scattered extraformational conglomerates. The Huntley Mountain Formation does not display this degree of lithologic variety. Further, the Rockwell Formation does not appear to have fining-upward cycles, whereas the Huntley Mountain does. The Rockwell does not have the preponderance of greenish-gray flaggy sandstone that the Huntley Mountain does. An arbitrary vertical cutoff between Huntley Mountain and Rockwell is defined at 41° north latitude. Eventual adjustment of the geographic location of this vertical cutoff may result from more detailed mapping.

The Huntley Mountain Formation is the approximate equivalent of the upper half of the Sunfish Formation as defined by Woodrow (1968).

The western limit of the Huntley Mountain is roughly the western limit of post-Catskill nonmarine deposition. This is a complex interdigitation of marine and nonmarine strata that is difficult to delineate. For purposes of revising the 1980 state geologic map a zone about 7 to 8 km (4 to 5 mi) wide was established which represents the average horizontal space which was required to accomplish complete regression and change to the marine succession of western Pennsylvania. In essence, this zone is a nonvertical arbitrary cutoff. The zone runs southward from western Potter County through central Cameron County, changes to a westward trend in eastern Elk County, and crosses the northwest corner of Clearfield County. The southward continuation of this zone of regression is a subsurface problem which is not yet resolved. Detailed mapping of this lateral transition in Pennsylvania will probably

result in an intricate stratigraphic subdivision reflecting interbedding of offshore marine clastics and nonmarine delta-plain sediments. The Devonian Oswayo Formation includes gray and olive-green shales, interbedded with thin siltstones and sandstones. Fossil brachiopods and other marine fossils are abundant. The Mississippian formations above the Oswayo Formation incude (upward) the Cussewago Sandstone, Bedford Shale, Corry Sandstone (Berea Sandstone farther west), Cuyahoga Group, and Shenango Formation. These formations are a dominantly marine succession. Parts of the Shenango may be of lower delta plain origin. The Huntley Mountain Formation is the dominantly nonmarine lateral equivalent of the marine Oswayo and overlying marine Cussewago through Shenango.

Over part of Tioga and Bradford Counties, the Pottsville Group rests unconformably on the Huntley Mountain Formation. The contact between the massive, white to light gray, conglomeratic basal sandstones of the Pottsville, and the medium-to-fine-grained, flaggy, greenish-gray to light-olive-gray sandstones of the Huntley Mountain is very easy to recognize.

The Huntley Mountain Formation is Late Devonian and Early Mississippian in age. Fossil plants, trace fossils, and fossil invertebrates which have been collected have not yet been studied in sufficient detail to pin down the exact position of the systemic boundary. Berg and Edmunds (1979) discuss the paleontology and age of the Huntley Mountain in more detail. The presence of fining-upward cycles, predominant trough crossbedding style in the sandstones, fossil plants and roots, and fossil freshwater invertebrates all point to an alluvial environment of deposition for the Huntley Mountain Formation. In the zone where the Huntley Mountain passes to the west into the marine Oswayo-through-Shenango succession, interpreted depositional environments are complex, and probably involve nearshore, tidal-flat, and lower delta plain environments.

The fining-upward cycles of the upper part of the underlying Catskill Formation are the result of deposition by a meandering river system. The upper fine elements in the Catskill cycles are red shales and siltstones, and these were deposited on overbanks during periods of flooding. The lower coarse elements in Catskill cycles are crossbedded or planarbedded gray and red sandstones, locally containing some intraformational conglomerate; these were deposited as channel sediments during normal river flow. The fining-upward cycles are preserved in meander systems because channels maintain their position long enough for floodplain deposits to become stabilized and vegetated.

In contrast to meandering-river systems, braided-river systems are characterized by rapidly changing flow conditions, a paucity of fine-grained overbank sediment, and ephemeral channel patterns. The Burgoon Sandstone is probably the result of deposition in a braided-river system. Fine overbank shale or siltstone in fining-upward cycles is lacking in the Burgoon. However, thin, random shale lenses do occur in the Burgoon, as do shale clasts. The crossbedding observed in the Burgoon is well developed and consistently in trough-shaped sets. Cut-and-fill structures are common. The ancient environments responsible for Huntley Mountain deposition are probably transitional between those attributable to the Catskill and to the Burgoon. In all likelihood, because of the presence of fining-upward cycles, the major depositional environment of the Huntley Mountain was a meandering-river system that was carrying a greater average sand load than the Catskill meandering

river system. The upper fine (overbank) elements of Huntley Mountain cycles are thinner in general than those of Catskill cycles; lower sand (channel) elements are thicker than those of Catskill cycles. Overbank deposits were given less time to stabilize, and channel stability was lower, leading to more rapid migration of meanders. Channelways were more ephemeral and lower in sinuosity than Catskill channels, and a braid system was approached during Huntley Mountain time. The upper parts of the Huntley Mountain may in fact contain some true braided-river deposits--precursors of the Burgoon braided-river system.

The Huntley Mountain Formation was deposited in the restricted extreme northern end of the Appalachian basin. The setting was more distant from the Acadian source area to the east and southeast than in the case of the correlative Spechty Kopf and Rockwell Formations. In addition, the Huntley Mountain may have been receiving some input from the older Taconic highlands to the northeast, and possibly from the craton to the north.

Sediments of the Huntley Mountain Formation were deposited upon the upper surface of the vast red delta complex of the Catskill Formation. The Catskill delta complex and its westward marine equivalents were essentially a prograding depositional sequence which achieved maximum eastern extension during the late part of the Late Devonian (Chautauquan). At that time, a widespread and relatively abrupt marine transgression overran the upper surface of the Catskill delta complex, resulting in the deposition of the marine Oswayo Formation. This transgression is somehow reflected farther to the east by the change from Catskill deposition to Huntley Mountain deposition. How the greater sand input and presumed increased streamflow velocity of the Huntley Mountain depositional system is related to an abrupt transgression farther west is not clear at present. Perhaps increased precipitation and a rise in sea level are linked at this moment of geologic time.

MISSIPPIPPIAN-PENNSYLVANIAN DISCONFORMITY AND PENNSYLVANIAN STRATIGRAPHY

by
W. E. Edmunds

THE DISCONFORMITY

During early-middle Mississippian time (Osage Epoch) the Burgoon Sandstone and the upper part of the Huntley Mountain Formation, which seems to be laterally equivalent to the Burgoon on the north, were deposited across north-central Pennsylvania. Following this, in late-middle Mississippian (Meramec Epoch), early elements of the red clastics of the Mauch Chunk delta were deposited from the southeast while, shortly after, the embayment in which the Loyalhanna Sandy Limestone was deposited encroached from the southwest as far as Lycoming and Sullivan Counties. At the same time as the Loyalhanna transgression, northern Pennsylvania and adjacent New York were subjected to epeirogenic uplift and erosion of the upturned edge of the early Mauch Chunk, Burgoon, Huntley Mountain, and lower units occurred. This uplift blocked extension of the Loyalhanna to the north and northwest and provided much of that unit's sand fraction (Edmunds and others, 1979).

By late Mississippian (Chester Epoch), clastics of the resurgent northwestward-prograding Mauch Chunk delta had overrun the Loyalhanna embayment across central Pennsylvania and encroached for some undetermined distance onto the northern uplifted area. The present northern limit of the Mauch Chunk Formation lies across northern Lycoming County, south of the Barclay Syncline (Berg and others, 1978). It is not clear whether this northern limit represents the approximate maximum northern progradation limit of the Mauch Chunk delta or whether these sediments originally extended considerably farther north and were subsequently cut back to the present position by renewed erosion in northern Pennsylvania at the end of the Mississippian and beginning of the Pennsylvanian Periods. Similarly, it is unclear to what extent the Mississippian-Pennsylvanian erosional disconformity extends to the south upon the upper surface of the Mauch Chunk Formation itself.

Within the parts of Tioga and Bradford Counties covered by this field trip, Pennsylvanian units rest disconformably upon Lower Mississippian Burgoon Sandstone or Huntley Mountain Formation. The northern limit of the Burgoon lies roughly along the course of the Wellsboro anticline. South of that line the Lower Pennsylvanian Pottsville Formation rests upon Burgoon, while to the north the Pottsville is underlain by Huntley Mountain Formation.

The exact nature of the northern termination of the Burgoon is not completely clear. Undoubtedly, it is being beveled off to the north by the Mississippian-Pennsylvanian disconformity. There is also some possibility that the Burgoon is also passing by lateral facies change into a northern upward extension of the normally subjacent Huntley Mountain Formation. The evidence for this lateral Burgoon-Huntley Mountain facies change is largely circumstantial. This situation occurs elsewhere around the periphery of the Burgoon lithosome (Edmunds and others, 1979, p. B9-B12). In addition,

Fuller and Alden (1903) report that their equivalent of the Huntley Mountain Formation (Oswayo Formation) is up to 1000 ft thick in the Kettle Creek syncline in northwest Tioga County. One thousand ft is approximately the combined thickness of the Huntley Mountain and Burgoon to the southeast.

Erosion of the Tioga and Bradford County area continued into early Pennsylvanian time (Morrow Epoch). During late Morrow and Atoka time alluvial sandstones and conglomerates of the Pottsville Formation were introduced from both the north and southeast, burying the erosion surface.

PENNSYLVANIAN STRATIGRAPHY

General Stratigraphy

The Pennsylvanian rocks of Tioga and Bradford Counties exist as isolated outliers in the deeper parts of the Barclay, Blossburg and Pine Creek synclines. The corresponding coal fields are named Barclay, Blossburg-Antrim, and Gaines (or Gurney) respectively. Maximum remaining thickness is somewhat over 300 ft in the Fallbrook-Morris Run area in the Blossburg syncline. The age of the sequence is estimated to be Upper Morrown through Desmoinesian.

As is typical of the Pennsylvanian, the sequence is a more or less hetrogeneous mixture of various clastic lithologies ranging from conglomeratic sandstone to claystone with interspersed coal beds. The basal contact of the Pennsylvanian is disconformable on the lower Mississippian Burgoon Sandstone south of the Wellsboro anticline axis, and the Huntley Mountain Formation north of the axis.

The lower 50 to 100 ft of the Pennsylvanian is usually occupied by a prominent sandstone and conglomerate. Because the underlying Burgoon is also a sandstone, often slightly conglomeratic, and the Huntley Mountain is largely sandstone, the base of the Pennsylvanian is often difficult to locate in poorly exposed or poorly described sections.

This basal conglomeratic sandstone is further complicated by the fact that it has a dual source, being introduced both from the north and the southeast. The southeastern source was the orogenic highlands located in the vicinity of Philadelphia, and as such is an extension of the conglomerates of the Sharp Mountain Member of the Pottsville Formation of the Anthracite area and equivalent to the Connoquenessing sandstones of southwestern Pennsylvania. The northern source was the margin of the cratonic area of Canada and New York (Fuller, 1955; Meckel, 1964, 1967), and is a continuation of the Olean and Sharon conglomerates of the Pottsville Formation of northwestern Pennsylvania, New York, and Ohio. This relationship is similar to that shown in a more regional sense by Meckel (1964, 1967), and in Edmunds and others (1979, Fig. 13A) although Meckel's detail in the crucial area of Tioga, Bradford, and Lycoming Counties is inadequate to produce a clear-cut boundary between the northern and southeastern Pottsville rocks.

The remainder of the Pennsylvanian sequence is correlated mostly on the position of coal seams or coal complexes. The coal beds are used because of their economic importance, more frequent exposure, and the erroneous assumption that coal seams are generally persistent key beds in contrast to

the remainder of the section which has great lateral variability. The customary Pennsylvanian stratigraphic sequences for each of the three coal basins are shown in Figure 7. They should be taken as generalized guides rather than uniform stratigraphic representations. It is likely that the Bloss coal complex of the Blossburg-Antrim Field (which probably includes the Bear Creek coal as well) is a persistent coal zone although individual beds within the complex may not be continuous. The "B" coal of the Barclay Field and lowest coal of the Gaines Field are probably correlatives of the Bloss complex. Coal bed nomenclature is probably more persistent than the individual beds themselves, so that different coal seams falling at roughly the same stratigraphic position receive the same name even though they are not exactly correlative.

Regional Correlations

If local correlations are difficult, the problem of regional stratigraphic correlations between the North-central Coal Fields of this area and the Main Bituminous Field and the Anthracite Coal Fields are even more obscure. Speculation on this matter, both in formal publications and informally among geologists who have worked in this area for the last century and more, is commonplace; but substantial documented evidence is virtually nonexistant.

Almost certainly, the sandstones and conglomeratic sandstones in the basal part of the section correspond with the basal sandstones and conglomerates of the Main Bituminous Field/or the Northern Anthracite Field or both. As noted previously , these sandstones and conglomerates have a dual source with the northern source being an extension of the Olean Conglomerate and the southern source a continuation of the Sharp Mountain Member of the Anthracite area Pottsville Formation. This immediately produces a chronological correlation problem, as the Olean conglomerate is considered to be late Morrowan age, while the Sharp Mountain is Atokan to early Desmoinesian (Moore and others, 1944; Edmunds and others, 1979, Fig. 5). These ages are based upon paleobotanical studies (White, 1900; Read and Manay, 1964). White (1904) specifically states that the Sharon was probably not deposited in the Northern Anthracite Field or the north-central bituminous fields.

The Bloss coal complex customarily has been correlated with the Lower Kittanning coal complex of the Main Bituminous Field and the Red Ash-Buck Mountain coal of the Anthracite area. This correlation has been repeated for well over a century, but published proof is almost totally lacking.

On a strictly lithostratigraphic basis, the lower part of the Pennsylvanian sequence of the Northern Anthracite Field resembles that of the North-central Fields. In both, the lowest major coal (Bloss in the North-central Fields and Red Ash in the Northern Anthracite Field) closely overlies about 100 ft of sandstone and conglomerate.

The supposed corresponding section from the Main Bituminous Field is considerably dissimilar. The top of the basal sandstone and conglomerate sequence lies 120 to 150 ft below the Lower Kittanning coals with two other major coal complexes intervening (Mercer and Brookville-Clarion).

If the Lower Kittanning-Bloss-Red Ash (Buck Mountain) correlation is correct, it would seem to support the concept that the north-derived Olean-

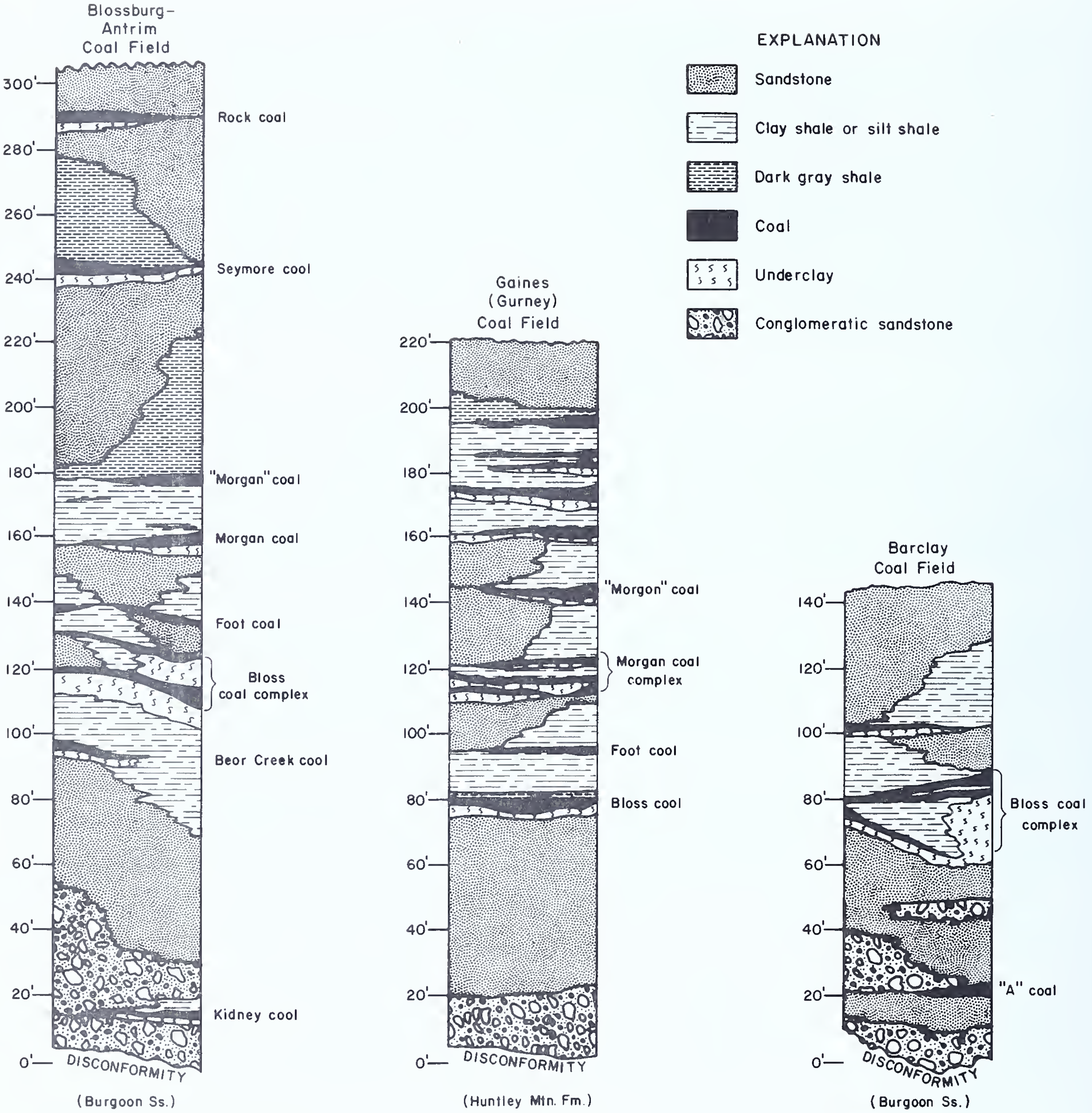


Figure 7. Generalized Pennsylvanian stratigraphic columns of the Blossburg-Antrim, Gaines, and Barclay coal fields.

Sharon conglomerate temporally preceded the south-derived Sharp Mountain Member of the Pottsville. In this case, the Mercer and Brookville-Clarion coal intervals of the Main Bituminous Field would be laterally equivalent to the Sharp Mountain sandstone and conglomerate. These relations are based upon partially complete paleobotanical correlations and contain some *a priori* assumptions and possibly a certain amount of circular reasoning.

The recent discovery by T. M. Berg of a sparse, but distinctly marine and brackish invertebrate suite in the dark shales above the Seymore coal in the Blossburg-Antrim coal field introduces additional correlation problems. If it is assumed that the Bloss coal is equivalent to the Lower Kittanning of the Main Bituminous Field, then, on interval, the Seymore should be at the position of the Upper Kittanning coal which has no known occurrence of marine or brackish fauna in western Pennsylvania.

Application of stratigraphic nomenclature to Pennsylvanian rocks of the area hinges on final correlation to either the Main Bituminous Field or the Anthracite area. The nomenclature of either could be used, although it has been customary to try to apply that of the Bituminous area to the southwest. The Pennsylvanian sediments of the North-central Field span the Pottsville and Allegheny Groups of the Main Bituminous Field and the Pottsville and Llewellyn Formations of the Anthracite area.

It must be noted that the Bituminous Pottsville Group and the Anthracite Pottsville Formation have different upper key-bed boundaries, if the equivalency of the Lower Kittanning and Buck Mountain - Red Ash coal (or at the base of its underclay). In the Bituminous Field the top of the Pottsville is not at the base of the Lower Kittanning coal, but at the base of the underlying Brookville-Clarion complex. On this basis then, the stratigraphically equivalent position of the top of the Bituminous Pottsville falls somewhere in the upper part of the Sharp Mountain Member of the Anthracite Pottsville.

If, for the sake of an example, it is further assumed that the Bloss (or Bloss-Bear Creek) coal complex is equivalent to the Lower Kittanning-Buck Mountain (Red Ash) then the Anthracite Pottsville-Llewellyn boundary falls at the base of the Bloss or Bear Creek coal. It then follows that the position of the Bituminous Pottsville-Allegheny boundary would occur at some indeterminate point within the basal sandstone and conglomerate sequence.

It is clear that a number of serious correlation problems remain, and that a substantial amount of work remains to be done to resolve these questions.

Depositional Environments

The depositional environments of the Pennsylvanian sequence in the Tioga-Bradford County area have not been studied in any detail and at this time can only be inferred from the general character of the sediments and associated biota and from the position of this area in the generalized upper Morrowan through Desmoinesian paleogeography (Edmunds and others, 1979, Figs. 12 and 13).

During the long period of erosion from Upper Mississippian (Chesterian) through lower Morrowan, Lower and Middle Mississippian sediments were eroded and at least moderate relief was developed across the Tioga and Bradford County area. Following this, during upper Morrowan and Atokan time, approximately 100 ft of sand and pebbles were deposited across the area from both the north and southeast forming the basal Pennsylvanian rocks. Deposition from both sources was, almost surely, by anastamosing streams on an alluvial plain. The coarseness of the sediments indicates that the streams were at least intermittently high energy. Limited swamps or lakes developed in the interfluves allowed intervals of peat (coal) accumulation and deposition of fine clastics. Frequent stream channel relocations periodically destroyed these temporary environments.

During subsequent Des Moines time which corresponded to a marine transgression in western Pennsylvania, the regional depositional environment was altered to what is probably best classified as an upper delta plain. A single, brief marine incursion over the Seymore coal horizon left a sparse juvenile or impoverished fauna, and is the only indication of marine or brackish waters reaching this area.

The Bear Creek coal and most of the younger Pennsylvanian sequence probably represent the non-marine or upper distributary portion of one of the coalescing deltas fringing the marine embayment to the west. The coals were formed in the interdistributary areas beyond the stream channel levees. Individual swamp areas were buried as streams broke through their levees and formed new distributaries in the previous swamp position. Once stabilized in a new position, the distributary streams would develop levees, and marshes or coal swamps would then develop in the new interfluve areas.

GLACIATION IN NORTH-CENTRAL PENNSYLVANIA AND THE PINE CREEK GORGE

by
G. H. Crowl

INTRODUCTION

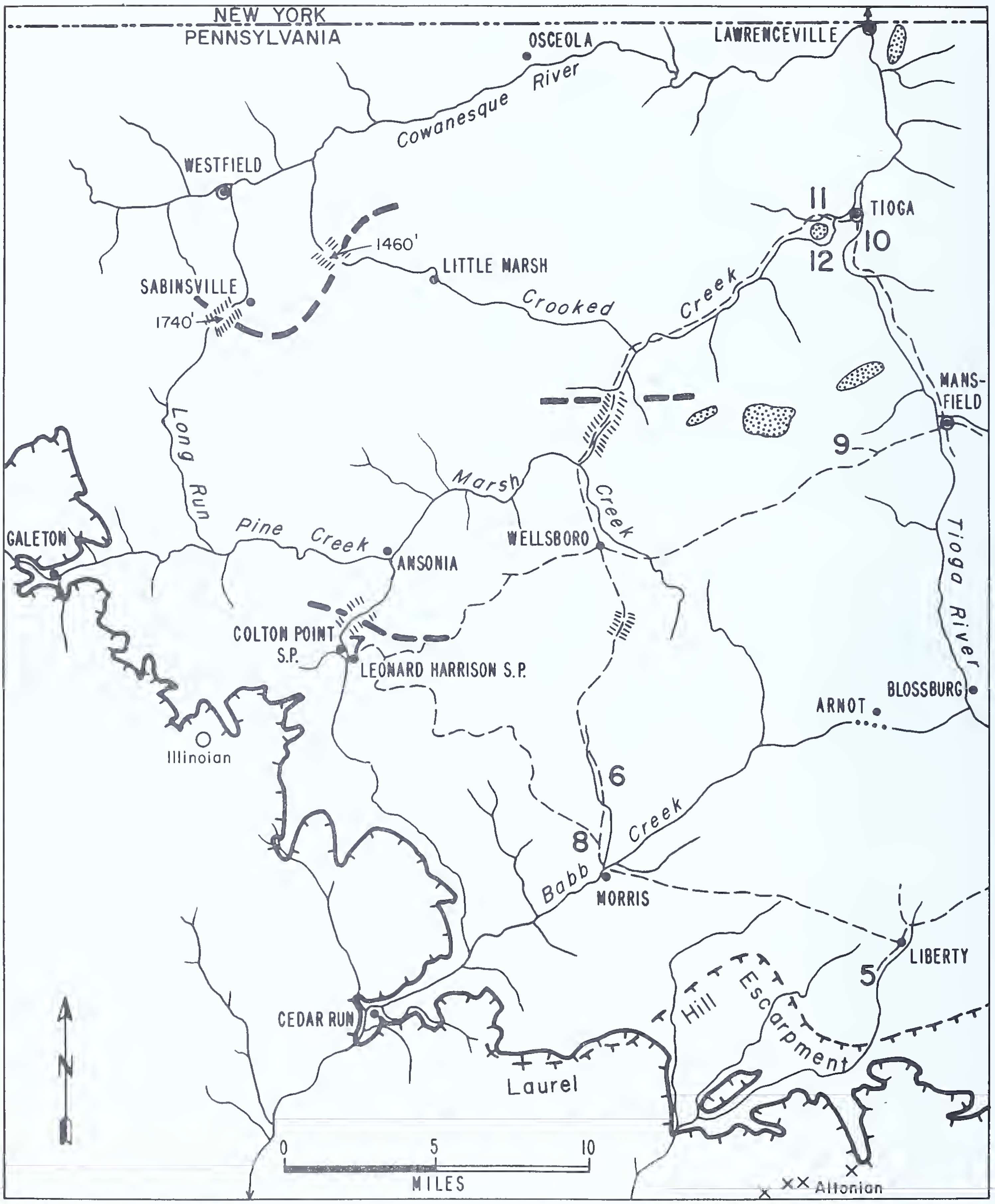
North-central Pennsylvania lies within the border of the last Wisconsinan glaciation, but it is not immediately apparent that the country has been glaciated. Till is irregular in thickness and distribution, and bedrock colluvium mantles many slopes. South-facing slopes are till-covered to a moderate depth; north slopes have thin till or colluvium; and hilltops generally have thin till, but thick till occurs locally. Generally, Olean drift rests upon bedrock. Only in a temporarily available stripping at the Antrim Mining Company operation northwest of Morris (Stop 8) has an older till been discovered beneath the Olean till. The relationships between these tills are not clear and are discussed in the text description for Stop 8.

Glaciofluvial deposits are essentially confined to the valleys. Valley-side kames occur in some valleys and outwash gravels underlie much of the recent alluvium in the large valleys. A discontinuous belt of kame moraine lies west of Mansfield and trends approximately east-west. All these kame areas occur in the valleys. Post-glacial lake clays underlie the floor of Cowanesque Valley north of the field trip area, and are comparable to well known deposits in the Genesee Valley, New York.

The present drainage pattern of north-central Pennsylvania is the result of normal stream action modified by pre-glacial stream piracy and Pleistocene glacial ponding of streams with concommitant stream diversion across divides.

Pine Creek, with its upper course in a broad, open valley and its lower course in a gorge, offers an outstanding example of drainage diversion by glaciation at Pine Creek Gorge. At Ansonia, Pine Creek leaves its eastward course in a broad pre-glacial valley and turns abruptly south into the gorge. Marsh Creek, a tributary from the east, is a reversed underfit stream in the central part of the pre-glacial valley. This valley, in turn, extends northeast to the Crooked Creek drainage (Figure 8). The Field Conference route on Day 2 returns to Wellsboro via the Crooked Creek-Marsh Creek valley, and the contrast between this valley and Pine Creek Gorge should be noted. Diversion of upper Pine Creek into the gorge and hence to the Susquehanna drainage is probably the result of Nebraskan glaciation.

A large post-glaical alluvial fan lies at the mouth of Ives Run (lunch stop, Day 2). Ives Run and its tributary, Stephenhouse Run, drain a narrow valley about 4 miles long in which there are several kames. Presumably these kames were easily eroded in early post-glacial times and the debris carried downstream to build the fan in Crooked Creek valley. Comparable fans occur elsewhere within the Woodfordian area.



Streams
Roads
Breached Divides
Through-valleys
Pirated preglacial stream course
Woodfordian glacial boundary
Kames and Kame moraines
Scarp
6 Field trip stops
× Altonian outcrops
○ Illinoian outcrops

Figure 8. Drainage network in north-central Pennsylvania.

GLACIATION

Olean drift is widespread in north-central Pennsylvania. It was deposited during the Late Wisconsinan (Woodfordian) glaciation, the last glaciation in Pennsylvania, between 22,000 and 15,000 years ago. The Olean drift border has been traced across the state from the New York-Pennsylvania boundary near Salamanca, New York, to the Delaware River near Belvidere, New Jersey (Crowl and Sevon, 1980).

Olean Till on red beds of the Catskill and Mauch Chunk Formation is reddish brown, usually 5YR4/4, and ranges from 2.5YR4/4 to 5YR3/3. It is sandy, often clayey, and with relatively low amounts of silt. Red fragments of the bedrock predominate in the till and crystalline erratics are essentially absent in the field trip area.

South of the Woodfordian border, colluvium covers most of the landscape, and there are only scattered deposits from earlier glaciations of Altonian (probably Mid-Wisconsinan) and Illinoian ages. No serious attempt has yet been made to map the occurrence or the borders of these older deposits in north central Pennsylvania west of Williamsport. All drifts are derived from the local bedrock, and erratics are rare. At and beyond the border, these 3 drifts are distinguished from one another by depths of weathering and development of the soil profile (Crowl and Sevon, 1980).

North of the Woodfordian border, little is known in detail about the glacial geology of the area because it has not been mapped at 1:24,000 scale. A few general studies have been made (Denny, 1956; Denny and Lyford, 1963) and a few detailed studies (Aber, 1980; Coates, 1966a). Most of the surface is underlain by a thin mantle of till and by colluvium. The till cover is thin and intermittent. Areas of colluvium are interspersed among the areas of ground moraine and are probably more abundant on north-facing slopes where till is thin or absent. It is not immediately clear that any one slope is till or bedrock colluvium for till is made almost exclusively of local bedrock. The presence of more-or-less rounded fragments of rock indicates till; angular fragments generally indicate bedrock colluvium. However, the presence of colluviated till on steep slopes complicates interpretations.

Coates (1966a, 1974) has described "till shadows" on the south-facing slopes of hills in the plateau in New York. The till cover is thick on south-facing lee slopes and thin or absent on north slopes where ice flow was effective in erosion. The till thickness in such "shadows" increases from the crest of the hill southward into the valley and the stream may be displaced southward. Colluvial north slopes may be more abundant in Pennsylvania than in New York.

Abundant deposits of kame gravels lie in the valleys of Tioga River, Crooked Creek (Stops 11, 12), and Cowanesque River north of the field trip area. Most of these are valley-side kames which were deposited in melt water bodies between the rock wall and the ice wall as the glacier melted.

A kame moraine in Crooked Creek valley (Stops 11, 12) near Tioga is a "valley choker" kame (MacClintock and Apfel, 1944). The ice stagnated at

this position during back wasting and melt waters built extensive sand and gravel deposits near the front margin. The lower part of the moraine is composed of gently dipping silts and sands and the upper part of steeply dipping sands and gravels (Corps of Engineers, n.d.). At that time, a pro-glacial lake may have extended southwest down valley about 8 miles to the vicinity of Niles Valley. Here the present divide within the valley is at an elevation of 1280 feet, about the same elevation as the top of the kame. No lake beds are yet known in the valley southwest of the kame and it may well be that the lake in which the gravel accumulated was formed within the ice and was not much larger than the kame.

THE PINE CREEK GORGE AND OTHER DRAINAGE DIVERSIONS

Pine Creek Gorge, the "Grand Canyon of Pennsylvania" extends from Ansonia, north of Leonard Harrison/Colton Point State Parks, about 50 miles south to the edge of the Allegheny Plateau which is in turn about 3 miles northwest of the Susquehanna River. Its greatest depth, about 1400 ft, is near Waterville, 10 miles northwest of the Susquehanna River. At Leonard Harrison/Colton Point State Parks the gorge is about 800 ft deep.

At the state parks the gorge is cut into rocks of the Upper Devonian Catskill Formation; farther south it crosses several broad anticlines and synclines where Devonian and Mississippian rocks are alternately exposed.

The present stream pattern is basically the result of successive piracies during the Mesozoic and Early Cenozoic as various drainage systems lowered their basins and enlarged them at the expense of others. For instance, Babb Creek, now tributary to Pine Creek, and the westward course of Tioga River at Blossburg are aligned in the Blossburg Syncline (Figure 8). An abandoned highlevel valley at Arnot separates the two drainages. Thus, lower Pine Creek (Babb Creek) originally rose in the present headwaters of the Tioga River at the east end of the Blossburg Syncline and flowed southwest down the syncline. These headwaters of Pine Creek were captured through headward erosion by the ancestral Tioga River, and Babb Creek was shortened (Ashley, 1945).

Prior to an early glaciation, the divide between upper Pine Creek-Marsh Creek-Crooked Creek drainage to the north and lower Pine Creek to the south lay along the present height of land about a mile north of Leonard Harrison/Colton Point State Parks (Figure 8). The present course of middle Pine Creek lies on the sites of two opposed pre-glacial tributaries flowing from the divide. A tributary flowed north to the upper Pine Creek-Crooked Creek drainage, and Middle Pine Creek occupied its present site and flowed south. Presumably a col lay in the divide between the two streams.

This sequence of events is suggested for development of the present drainage: the advance of an early ice sheet into Pennsylvania blocked north-and east-flowing streams and melt-water lakes formed in the valleys. The lake in upper Pine Creek-Crooked Creek valley drained through the col into middle Pine Creek. Abundant water flow, a steep gradient south of the col, and severe frost action associated with ice-marginal periglacial conditions would have severly broken these well-jointed rocks, and stream

erosion would have been very effective at the site. Continued advance of the ice obliterated the lake, covered and scoured the divide. With retreat of the ice front, a second lake was formed north of the divide, and further downcutting of the outlet took place. This process was probably repeated in successive glaciations to establish the present course of Pine Creek.

Similar diversions have occurred on larger and smaller scales in northwest Pennsylvania and in Ohio, and some are responsible for the present course of the Ohio River. Flooding, overflow, stream erosion, and ice erosion were repeated in successive glaciations to produce the present drainage pattern. Because Pine Creek Gorge was close to the margin of the ice, stream erosion probably was more effective than usual during the last glaciation and downcutting was enhanced.

Dating of the diversions presents some problems, for direct evidence in the region is almost absent. According to Alden (in Fuller, 1903) Pine Creek diversion occurred in Pre-Illinoian time, probably as a result of Kansan glaciation. This timing of glacial diversion in north central Pennsylvania coincided with Deep Stage diversion in northwest Pennsylvania and in Ohio when the ancestral Allegheny drainages and the Teays River in Ohio were disrupted and the present Ohio River drainage established. According to Stout, Ver Steeg, and Lamb (1943) the Deep Stage drainage episode was inaugurated by a Kansan or Pre-Kansan glacier and brought to a close by the Illinoian glaciation. Its main features are: the development of many new streams, deepening of most channels below the preceding stream beds, steep slope of valley walls, lack of reduction of side streams, and general immaturity of the basins. Coates (1966b) reported that a well near Osceola in Cowanesque Valley penetrated 245 feet of predominantly stratified drift, but failed to reach bedrock. This is the best evidence yet uncovered for Deep Stage erosion in north-central Pennsylvania.

Leighton and Ray (1965), and Ray (1974) presented evidence for diversion of the Ohio River during Nebraskan glaciation, and Swadley (1979) has described deeply weathered drift at low elevations close to the Ohio River in Kentucky. On the bases of deep weathering and low elevation he assigns these outcrops to a Kansan age and thus dates the drainage change as Nebraskan. It would seem, for lack of evidence to the contrary, that major drainage changes in Ohio and Pennsylvania occurred about the same time, and this recent evidence indicates a Nebraskan age.

Late Wisconsinan ice advanced over the north end of Pine Creek Gorge, but farther south, near Blackwell, the west wall of the gorge was a barrier to ice advance onto the plateau to the west (Crowl and Sevon, 1980). An ice tongue extended southwest down-valley beyond Cedar Run where Late Wisconsinan till and ice-contact gravels just above stream level mark the boundary. Denny (1956) noted gravels farther downstream in the vicinity of Slate Run. He provisionally assigned a Sangamonian age to a paleosol developed on the gravels and thus an Illinoian age to the gravels.

This historical sketch is opposed to that of Coates and Kirkland (1974) who argue that because of the rugged character of the gorge it is a single-cycle sluiceway cut during the Woodfordian glaciation. It is true that it shows little sign of glacial abrasion, but it is close to the ice margin and nearly parallel to it so that ice erosion would have been

ineffective (Fig. 8). Furthermore, recent mapping (Crowl and Sevon, 1980) show Altonian and Illinoian exposures south of the Woodfordian border. Thus repeated episodes of flooding and cutting, as outlined above, are more probable.

Comparable pre-glacial lakes and stream diversion have occurred elsewhere in this region. The Glacial Genesee Lakes, as indicated by lake clays in the valley bottoms with accompanying stream diversion to Allegheny River drainage, are well-known (Fairchild, 1895). The Cowanesque Valley, draining east to the Tioga River at Lawrenceville, was also the site of a Late Wisconsinan proglacial lake as indicated by lake clays in the valley (Willard, 1932). The lake drained through outlets near Sabinsville and Little Marsh, at successively lower elevations eastward, into the Pine Creek and Crooked Creek drainages until the ice front retreated beyond Cowanesque Valley and allowed drainage into the Tioga Valley to be re-established. In this case diversion did not last long enough to divert the Cowanesque River to either of the other drainages. These temporary outlets were probably first deepened during earlier glaciations.

The oldest radiocarbon ages of wood fragments recovered from the lake clays in the Genesee Valley range from 9090 to 9590 YBP (W4213, W4211), and in the Cowanesque Valley two dates on wood in lake clays are 1000 and 1270 YBP (W4252, W4307). All these dates are clearly two young to be related to post-glacial lakes, and are thought to result from incorporation of trees into lake clays by slumping at a late date. Such slumping is well displayed in the clays in the Genesee and Cowanesque valley.

Coates (1974), Coates and Kirkland (1974), and Crowl and Sevon (1980) give extensive lists of references.

A MAJOR(?) THRUST FAULT AT TOWANDA, PENNSYLVANIA: AN EXAMPLE OF FAULTING WITH SOME SPECULATION ON THE STRUCTURE OF THE ALLEGHENY PLATEAU

by
H. A. Pohn and T. L. Purdy*

INTRODUCTION

Faults which propagate through to the surface of the Allegheny plateau in north-central Pennsylvania may be easily missed by the field geologist because of poor outcrops, the paucity of key beds, and the lack of knowledge of the detailed stratigraphy of the pervasive Upper Devonian Lock Haven Formation. This paper discusses an example of a well-exposed, relatively large displacement fault in the plateau and attempts to set this fault into the regional tectonic framework of plateau folding and faulting.

ALLEGHENY PLATEAU AND VALLEY AND RIDGE FOLDS

The difference between Allegheny plateau and Valley and Ridge folds is widely known and has been discussed, notably by Price (1931), Butts and Moore (1936), Gwinn (1964), and since 1964, others too numerous to mention.

Folds in the Valley and Ridge province characteristically have shallow to moderately dipping south or southeast limbs (generally about 30°) and steeply dipping to overturned north or northwest limbs. We believe that some and perhaps much of the overturning of the north or northwest limbs in the Valley and Ridge is due to buttressing of the north limbs against splay faults that originate from a master decollement at depth.

Folds in the Allegheny plateau on the other hand are generally composed of broad open synclines and narrow anticlines. The limbs of the plateau folds are commonly nearly symmetrical and rarely dip more than a few degrees. The south limbs of some anticlines may be slightly steeper than the north limbs.

At depth, the Allegheny plateau anticlines are cored by uplimb thrusts and have depressed axes as first described by Gwinn (1964). These structures are frequently termed "tepee structures" by petroleum geologists (Figure 9). According to proprietary seismic data, the major controlling faults that core the anticlines appear to be antithetic.** The uplimb thrusts are listric and arise from the master decollement, which is commonly confined

* U. S. Geological Survey, Reston, Virginia.

** Antithetic faults in this area are north-dipping thrust faults whose hanging walls are displaced southward. Synthetic faults are south-dipping thrust faults whose hanging walls are displaced northward.

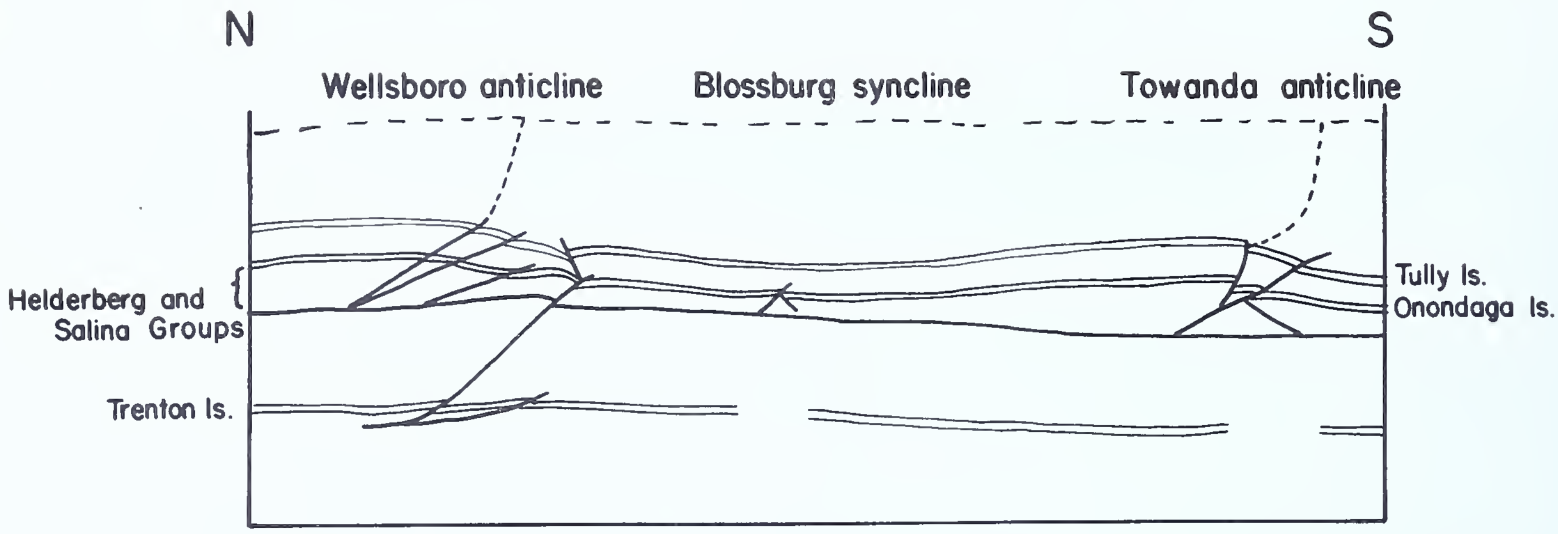


Figure 9. Seismic section (interpreted from proprietary data) of a part of the Allegheny plateau in Pennsylvania. Note the thickening of the beds of the Helderberg and Salina Groups in the cores of the anticlines. Uplimb thrusts from the tepee structres.

to the Silurian salt beds of the Salina Group under the plateau. Curiously, the seismic data show that such tepee structures are also present below some of the synclines. The tepee structures under the synclines are considerably smaller than those that core the anticlines. Resolution of seismic data is too coarse to relate precisely details of the tepee structures to the decollement, but the synclinal tepees may be collapse structures that formed when the salt flowed away from the synclines into the cores of the adjacent anticlines (L. D. Harris, 1981, personal communication). An alternative explanation may be that the synclinal "tepees" are highly faulted stair-case type folds, such as those described by Pohn and Purdy (1979). These structures are termed "pop blocks" by some petroleum geologists.

ALLEGHENY PLATEAU FAULTING

Faults are rarely observed on the surface of the Allegheny plateau; however, the scarcity of faults may be an illusion brought about by the relatively poor exposures, the paucity of key beds, and the occurrence throughout much of the north-central plateau of the lithologically monotonous Lock Haven Formation. Because of the great thickness of the Lock Haven Formation (2200'+, Berg and Glover, 1976, p. 11), a thrust or high-angle fault on the plateau would have to have considerable displacement to be recognized unless the fault zone was itself exposed. A tear or strike-slip fault having no vertical components of movement would be even more difficult to recognize because of juxtaposition of similar beds and, in north-central Pennsylvania, the amount of displacement would be virtually impossible to determine.

Although many faults have been described in the subsurface, only three exposed faults that have stratigraphic displacements approaching 20 m have been described on the Allegheny plateau of Pennsylvania. Two of these faults have been inferred from juxtaposition of different units (Shaffner 1958, p. 76; Berg and Glover, 1976, p. 49); the third is the Bridge Street Towanda, fault in which the fault plane is exposed. Other faults that have moderate

to large probable displacement have been inferred by criteria such as anomalous dips (Ashburner 1880, p. 34; Cathcart, 1934; Pohn, 1981), joint spacing (Pohn, 1981), and the presence and orientation of pencil siltstones (Pohn and Purdy, unpublished data).

THE BARCLAY SYNCLINE-TOWANDA ANTICLINE FAULT SYSTEM

Perhaps the most interesting and structurally informative system of faults exposed on the plateau is that associated with the Barclay syncline and the adjacent Towanda anticline (Figure 10). From north to south, the system is composed of a series of small-displacement (0.5-5 m) antithetic and synthetic faults, which may not be genetically related to the rest of the system; a moderate-displacement (15-m-plus) antithetic fault; a series of small-displacement (10-cm to 1-m) antithetic faults; a probable antithetic fault of moderate to large displacment; and a southernmost series of small- to moderate-displacement synthetic faults. This fault system occupies the zone of maximum flexure between the Towanda anticline and its companion, the Barclay syncline.

The assumption of relative displacement of a fault is at least partly inferred from the observation that the maximum offset on a fault is generally proportional to the length of the fault trace on the surface. Thus, a fault whose surface trace extends for 30 km or more is unlikely to have a maximum offset of only a few centimeters or meters.

Small-Displacement Antithetic and Synthetic Faults at Towanda

A series of six small-displacement antithetic faults and one small-displacement synthetic fault is exposed in the U. S. Route 220 roadcut just south of the Bridge Street underpass at Towanda. The largest of the antithetic faults has a displacement of approximately 3 m; the smallest has a displacement of less than 0.5 m. The strike of the antithetic faults is N75°W, which is unlike the strike of other faults in the area. The two largest antithetic faults, both of which are paired, have minor splay faults and show conspicuous drag near the fault plane. The northernmost fault in the roadcut, the fault having the greatest displacement, shows characteristic "Z" folding of beds between adjacent faults (Figure 11). At one place, a synthetic fault of 60-cm displacement cuts and displaces an antithetic fault having 5 cm displacement (Figure 12), showing that, in this instance, the synthetic fault postdates the antithetic fault. The outcrop, which is approximately 300 m long, probably has at least 30 m of lateral shortening. If this outcrop is at all characteristic, then faulting alone can account for a shortening of 10 percent in the plateau rocks.

THE BRIDGE STREET, TOWANDA FAULT ZONE

The Bridge Street thrust-fault zone at Towanda may be one of the best exposed fault zones known on the Allegheny plateau of Pennsylvania. The faults of the system are antithetic, have a minimum stratigraphic displacement of 14 m, and a minimum lateral shortening of 30 m (Figure 13). The fault zone is composed of three faults; a small splay evolves from the lowermost

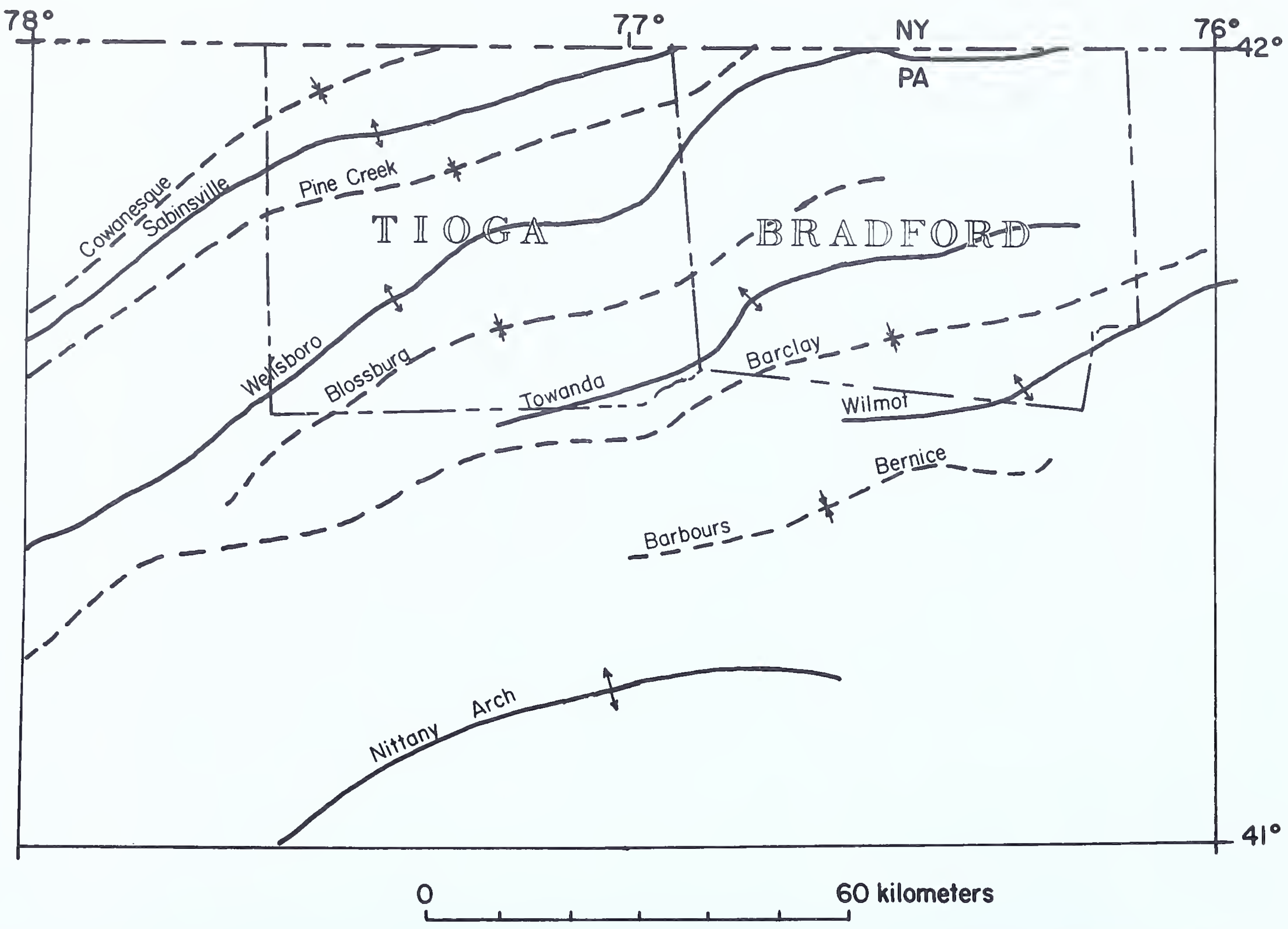


Figure 10. Map of the major anticlinal and synclinal axes on the Allegheny plateau (from Fettke, 1954).

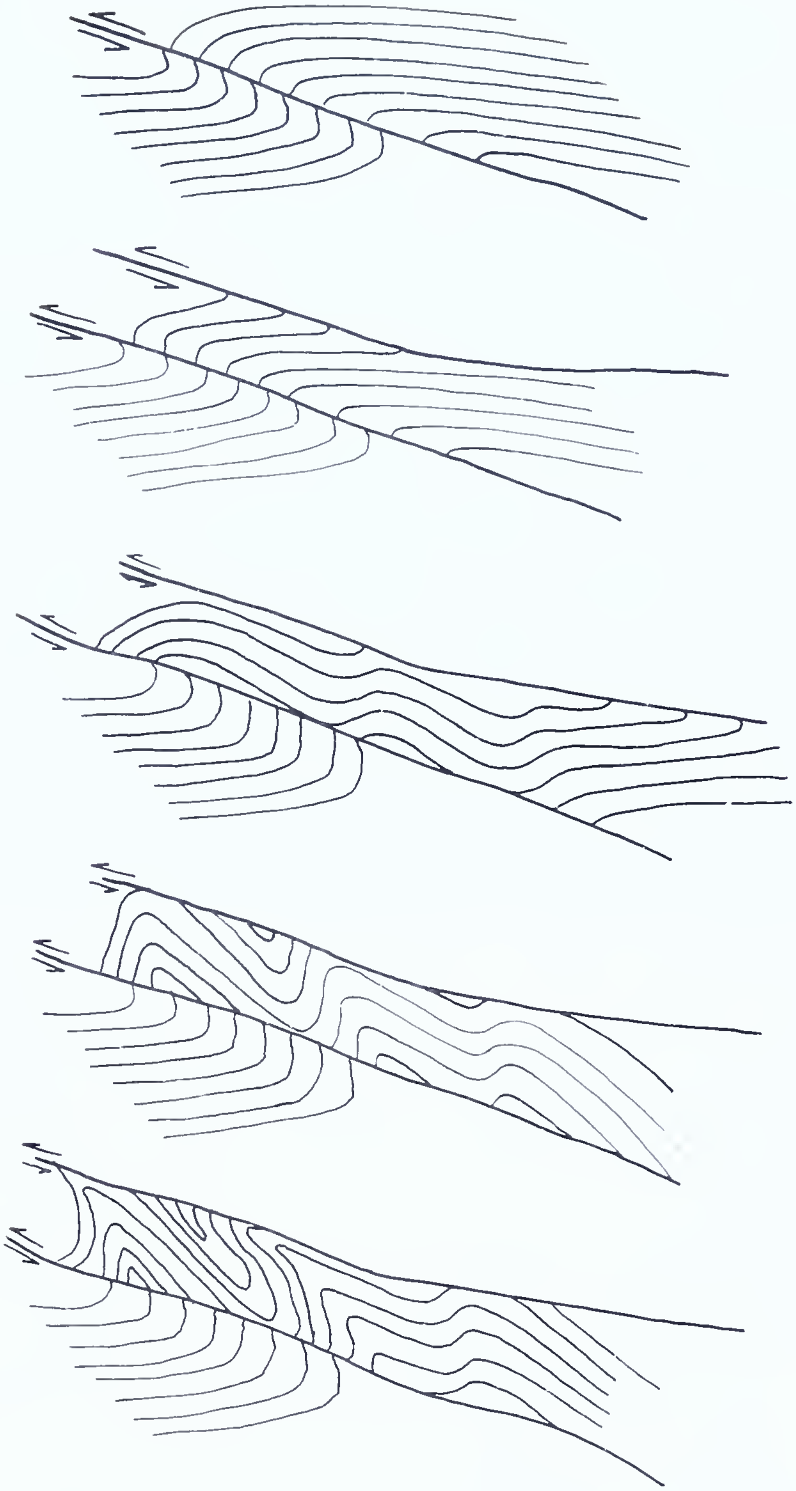


Figure 11. Schematic diagram of the evolution of disturbed zones or "Z" folds (example is the Bridge Street fault). Note that these are kink-type folds.

Figure 12. Photograph of part of the U. S. Route 220 roadcut just north of the Bridge Street fault. North is to the left. A 5-cm displacement antithetic fault is cut and offset by a 60-cm displacement synthetic fault at letter A. Arrows indicate faults.

fault. Paired or multiple faults are very common on the Allegheny plateau as well as in the Valley and Ridge province and may account for 70 to 80 percent of all thrust faults in the Appalachian foldbelt in Pennsylvania. Pairs of faults similar to the Bridge Street faults can be seen on the plateau at outcrops 0.95 km north of Franklin Center (7.5 km west-southwest of Towanda, Figure 14), at Three Falls Glen (20 km west-southwest of Towanda) and at Dogtown (see section below on synthetic faults). Each of these paired or multiple faults has a moderately to severly disturbed zone between the fault planes, including characteristic "Z" folding caused by drag. Presumably, the amount of disturbance is indictive of the amount of relative displacement between the two faults.

Although the Bridge Street fault is not seen again at the surface, we believe that the fault zone can be traced by the presence of acicularly cleaved siltstones (pencil siltstones) along its strike which is N80°E at

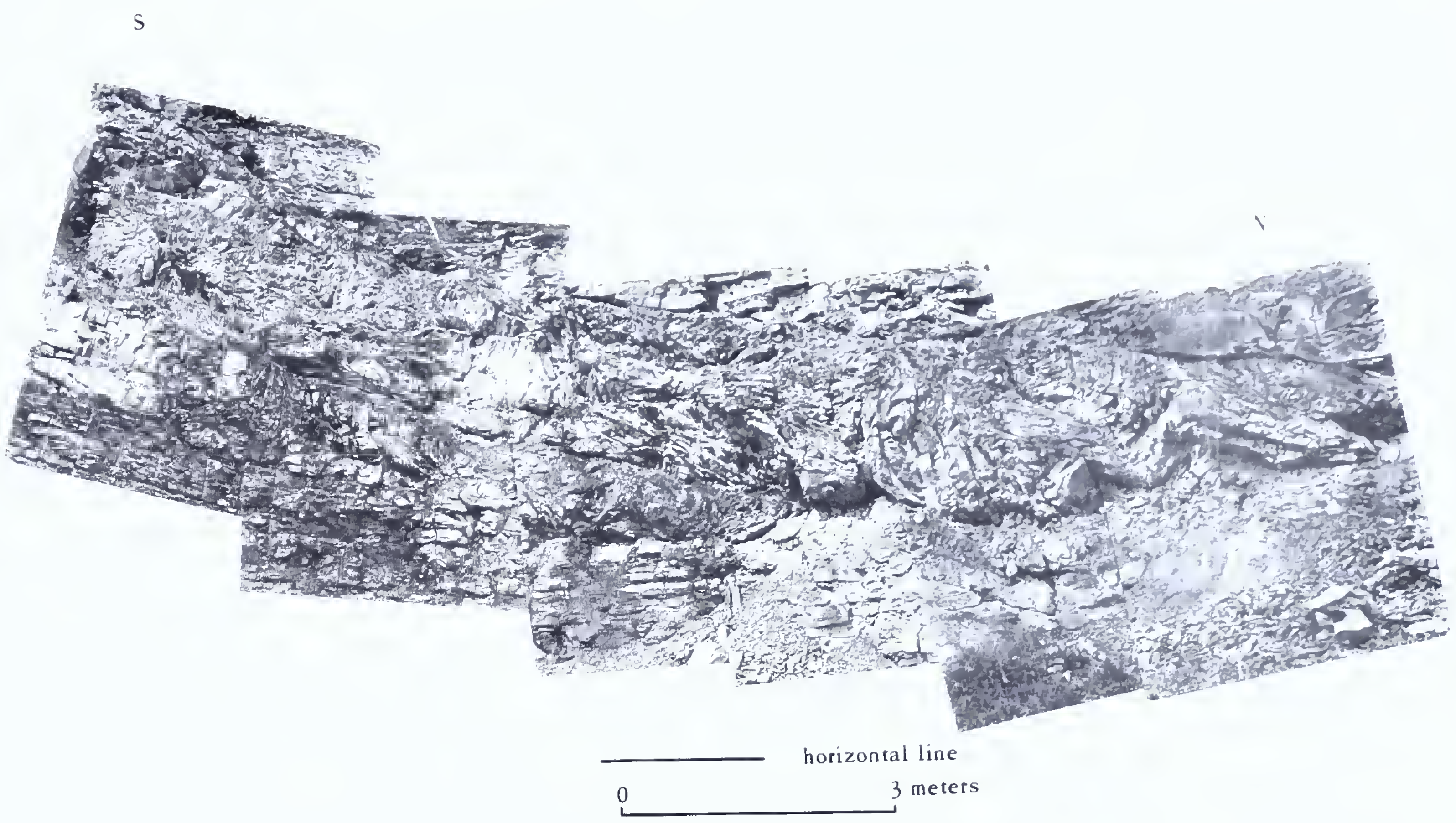


Figure 13. Photomosaic of the Bridge Street fault. Lower beds are horizontal.

Towanda. Twenty-two km southward along strike is an outcrop of pencil siltstones 0.5 km north-northwest of Granville Center (Figure 14). The direction of acicularity at the Granville Center exposure is N10°E. Continuing along the S80°W trend, pencil siltstones are present 30 km from the Bridge Street outcrop, 3.2 km northeast of the town of East Canton. There the "pencils" strike N64°E. At distances of 34.5, 41, and 49 km from Towanda are pencil siltstones whose strikes are N69°E, N64°W, and N69°E, respectively. All these pencil siltstone occurrences are aligned along a broad sinusoidal curve, which is subparallel to the front of the Barclay syncline; they probably mark the surface trace of the Bridge Street, Towanda, fault.

Small-Displacement Antithetic Faults Associated with Small Folds

A series of small cascade folds, which step downward to the south, is parallel to the front of the Barclay syncline and occupies the valleys of Towanda Creek and the Roaring Branch of Lycoming Creek. This series of folds can be traced from Monroeton to 5 km east-southeast of Liberty (Figure 14). Field excursions along the tributaries perpendicular to the strike of the folds show that the zone between the flat-lying beds and the adjacent steeply south-dipping beds is commonly broken by small antithetic faults. Along one roadcut southwest of Dogtown are 13 of these steplike folds; there may be several dozen folds in all. The displacement of any individual fault ranges from a few centimeters to as much as a meter, and

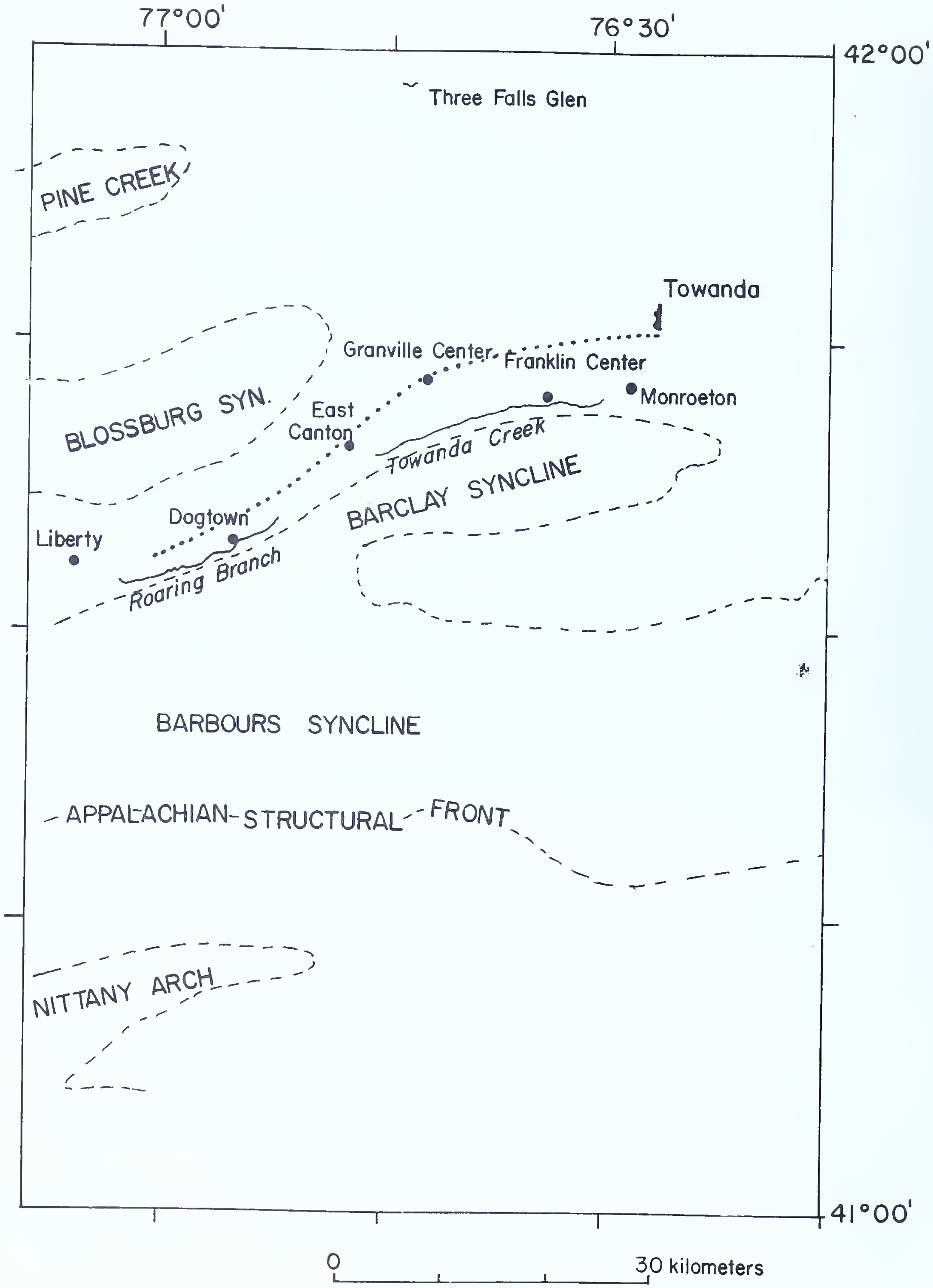


Figure 14. Index map, showing place names used in the text. Dashed lines indicate topographic expression of synclines and the Nittany arch. Dotted line represents probable surface trace of Bridge Street fault.

the total displacement of all the faults probably does not exceed 5 m (Figure 15).

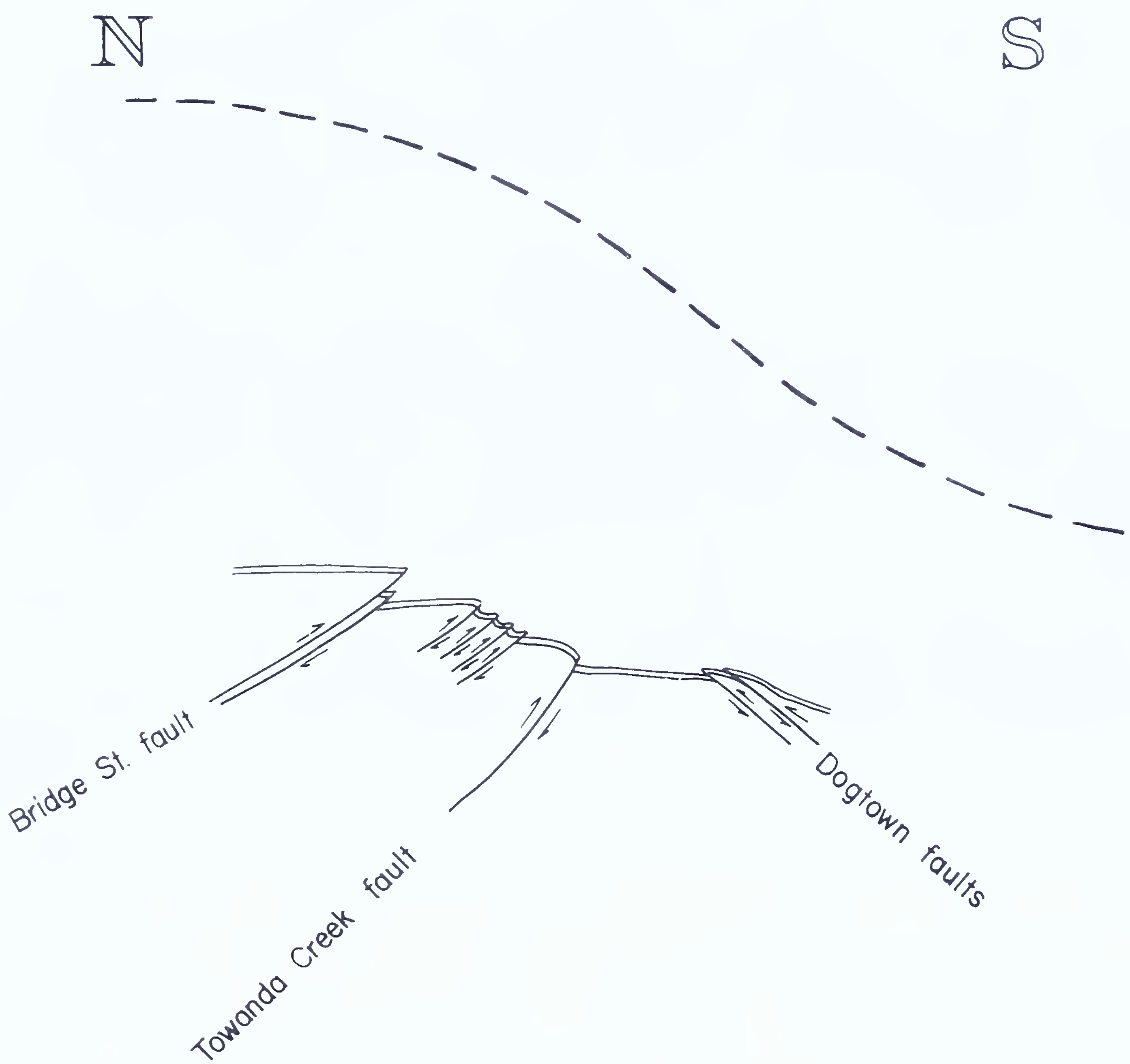


Figure 15. Schematic diagram of the flexure between the Towanda anticline and the Barclay syncline, showing the fault zones discussed in the text. Dashed line represents flexure.

MODERATE-TO LARGE(?)-DISPLACEMENT FAULT(?)

A moderate- to large-displacement fault may occupy the Valleys of Towanda Creek and the Roaring Branch of Lycoming Creek. Althouth the fault surface is never exposed, we hypothesize its presence because of the extremely steep dip of the beds adjacent to Towanda Creek and Roaring Branch. In addition, proprietary seismic data support the interpretation of an antithetic fault that cuts through the core of the Towanda anticline and breaks the surface along the creek valleys. An alternative hypothesis (Thomas Berg, oral commun.) proposes that the steeply dipping beds are part of a kink fold that

defines the northern edge of the Barclay syncline.

SYNTHETIC FAULTS OF SMALL DISPLACEMENT

Three synthetic faults of small displacement are exposed along the right-of-way of the old Penn-Central Railroad tracks 0.45 km east of Dogtown (Figure 14). The faults, whose displacements are only a few centimeters, may be part of a fault zone having larger displacement, because we traced the associated disturbed zone along strike to outcrops 2.2 km east of the Dogtown outcrop.

DISCUSSION

The faults and folds observed within the Barclay syncline-Towanda anticline couple may be unique on the Allegheny plateau, althouth at least one other anticline-syncline pair have oversteepened south dips on the anticlinal limb. The Wilmot anticline-Barbours, Bernice syncline pair shows dips ranging from 40° to 60° on the south limb of the Wilmot anticline. This anticline-syncline pair is south of the Towanda anticline-Barclay syncline system and is the last large anticline-syncline pair before the Valley and Ridge province.

We suggest that the stresses sufficient to produce the surface-penetrating antithetic faults in the two southernmost anticline-syncline couples were so reduced that the remaining stresses were insufficient to produce faults that penetrate the surface in the core of next anticline to the north (the Wellsboro anticline, Figure 16). Proprietary seismic data do, however, allow for the interpretation of an antithetic fault propagating to the surface. At present, we do not have data to show that the Wellsboro anticline-Blossburg syncline couple have associated faults that reach the surface. North of the Towanda anticline, outcrops become sparse and very poor.

Antithetic faults of the type described above have been illustrated by Gwinn (1964) much farther from the Appalachian structuraal front than those in the Towanda area. The faults shown by Gwinn are nearly identical with those mapped at the surface by Berg and Glover (1976) and by Shaffner (1958), and probably with the fault described by Ashburner in 1880. We believe that anticlines in north-central Pennsylvania may well be cored by faults like those that reach the surface in the southernmost folds but that fail to reach the surface in the more northerly folds.

If the above philosophy is correct, the fundamental difference in styles of deformation between the Valley and Ridge and the Allegheny plateau may be as follows: Under the Valley and Ridge, synthetic faults formed first and served as buttresses for folding, whereas under the Allegheny plateau, salt flowed into the zones and began to form anticlines, and in the process of forming the anticlines, stresses were generated that were released by the formation of antithetic faults. Thus, the difference in the two regions is not only that the major faults are synthetic rather than antithetic, but that the time of formation of the faults relative to the folds is different.

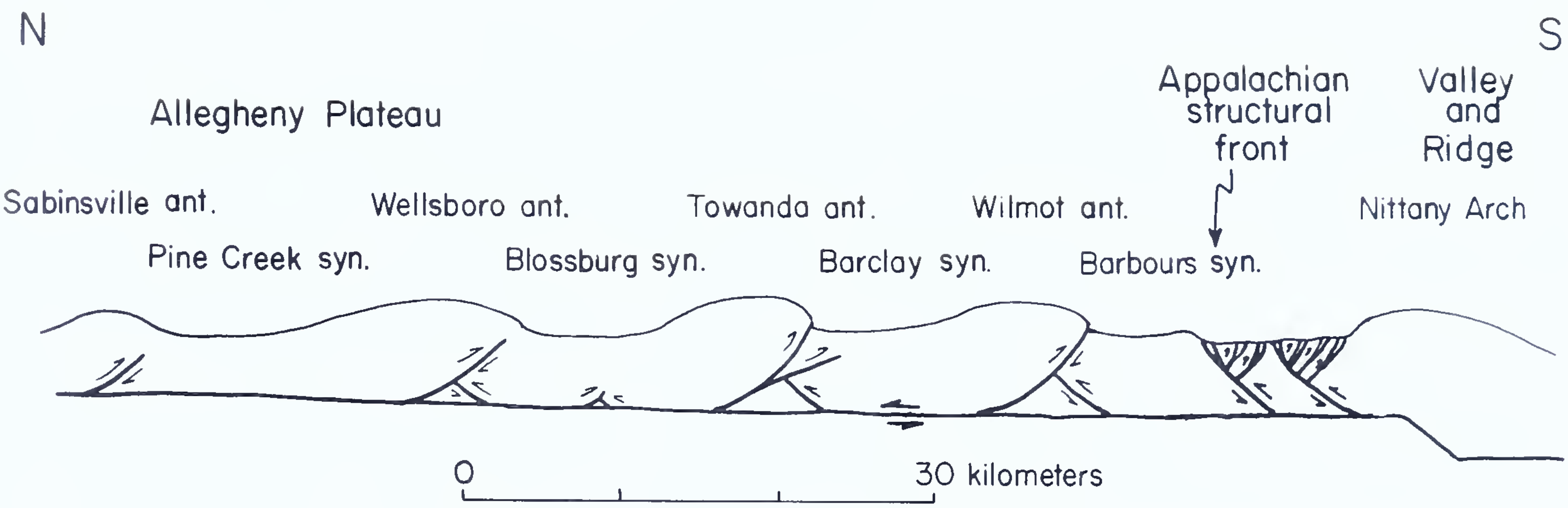


Figure 16. Schematic cross section illustrating authors' concept of part of the Allegheny plateau in Pennsylvania south from the New York border to the Nittany arch. The upper surface represents an idealized ground surface some time after the Alleghenian orogeny but before any erosion. Several times vertical exaggeration.

ECONOMIC GEOLOGY OF TIOGA AND BRADFORD COUNTIES

by
P. B. Luce and W. E. Edmunds

INTRODUCTION

When Tioga and Bradford Counties were first settled in the early 1800's, the counties were heavily forested, primarily with pine and hemlock. Logs and sawn timber were rafted south on Pine Creek and the Susquehanna River and north on the Tioga River. The hemlock bark supplied numerous tanneries. The deforestation (Plate 1, A) gave the First and Second Pennsylvania Geological Surveys access and exposures from which the basic stratigraphy and structure of the area was established.

Oil and gas, metallics, coal, and non-metallics will be approached historically and in a somewhat summary fashion. The greater activity in these areas in the past was a function of the economics and transportation system of the times. Some items of interest are only mentioned in passing.

OIL AND GAS

Earliest drilling in Bradford County began in June, 1865, and in 1866 some gas and oil were found in Tuscarora and Sylvania (Heverly, 1924); the 1883 and 1897 Tioga County histories (Anon.) give more details. In 1865, on Bear Creek 2 miles northwest of Tioga, a well 923 ft deep (cost $7,086.25) produced a small quantity of oil. The same year a dry hole 800 ft deep was drilled in Osceola and a well drilled on the Phillips farm (Westfield area) found large quantities of oil and gas. In 1877, a dry hole was drilled in Blossburg while limited quantities were produced from a well southwest of Elkland. In 1879 a dry well was sunk 1300 feet on Holden Brook northwest of Osceola.

The Gaines Oil Field was discovered in 1897. The Watrous pool extends about 2 miles westward from near Gaines with a width of 600 to 800 ft. The Manhattan pool is a small oval-shaped pool about ½ mile in diameter just to the east of the Watrous pool. The field is approximately midway between the axes of the Pine Creek syncline and the Marshlands anticline.

The Watrous pool (Figure 17) produced from a "Chemung" sand lying 700 ft below the top. This sand, the Atwell, averages 18 feet thick and produced an average of 5 barrels/day. Up to 40 barrels/day was the maximum initial production. The oil was free of water. The Atwell horizon is the lowest named sand horizon in the Lock Haven Formation in this area.

The producing horizon in the Manhattan pool was an alternating series of shaly sandstones, shales, shaly limestones, and thin limestones about 200 ft above the Atwell sand. The oil, with gas and salt water intimately associated, apparently occurred along fissures and bedding planes. Many wells were gushers and initial production varied from a few to 2,100 barrels/day.

A

PLATE I

Gas in the Atwell sand tended to concentrate in the upper part of the reservoir, but not in commercial quantities.

Dips of bedding within the field average about 3°N. Just north of the field surface dips approach 10°N. The accumulation was apparently induced by a terracing effect at the dip change on the flank of the anticline. The average depth of the wells is 700 to 800 ft, with none over 1000 ft (Cathcart and Myers, 1934). The nature of the Manhattan producing zone and the presence of saltwater suggests a deeper structural control for this pool rather than a simple local terracing.

The first deep gas production came in wild on September 10, 1930. The Palmer #1 is located on the Sabinsville anticline in Farmington township. Production commenced on October 11th, producing 22,000 MCF, R. P. 1665 psi, from the top of the Oriskany Sandstone. The well log shows it only penetrated the upper 7 ft of the Oriskany, and had a total depth of 4012 ft (Cathcart and Willard, 1931; Fettke, 1950). Sandstone samples blown from the well give an average porosity of 7.75 percent for the Palmer #1. Sixty one samples from 18 producers averaged 8.8 percent with a range of 2.9 to 11.8 percent. Porosity improved deeper in the formation, but the best pay was in the top 6 ft.

Analysis of the gas from Palmer #1 yielded (Cathcart and Myers, 1934):

Methane	99.5%	Sp. Gr.	0.58%
Nitrogen	0.4%	B.T.U.	1030
Oxygen	0.1%		

The East Tioga, West Tioga and Meeker (also spelled "Meaker") pools were discovered in 1930. The Sabinsville pool was discovered in 1935 (Lytle, 1963), and the Brookfield pool started production in Pennsylvania in 1938 (Fettke, 1950). These fields are on the Sabinsville and Harrison anticlines (Figure 18).

The Wellsboro anticline was tested and had only 2 small shows of gas. Neither the Slate Run or Marshlands anticlines show any indication of doming. A well defined dome on the Towards anticline, in Union Township, was drilled and is dry (Cathcart and Meyers, 1934). Figure 19 (Lytle, 1963, Pl. 12) shows a simple fault-controlled structural high for the Sabinsville pool. No wells were drilled to the Salina group in this area (Fettke, 1950, 1956; Lytle and others, 1961).

Figure 20 (Lytle, 1963) shows a much more highly complex Oriskany

Plate 1. A. Village of Morris Run, Pennsylvania, with colliery yard in foreground. Note deforested landscape. Photograph loaned by Tioga County Historical Society.

B. Miners at entrance to Pine Creek clay mine adit around 1900. Photograph loaned by Mr. Elwyn S. Lewis.

Figure 17. Oil derricks operating on the Watrous Pool in the town of Watrous, Pennsylvania, about 1897. View is to the northeast from a hill southwest of Watrous. The Atwell discovery well was just out of the picture to the upper right. Photograph loaned by Mrs. Allen W. Howland, Tioga, Pennsylvania.

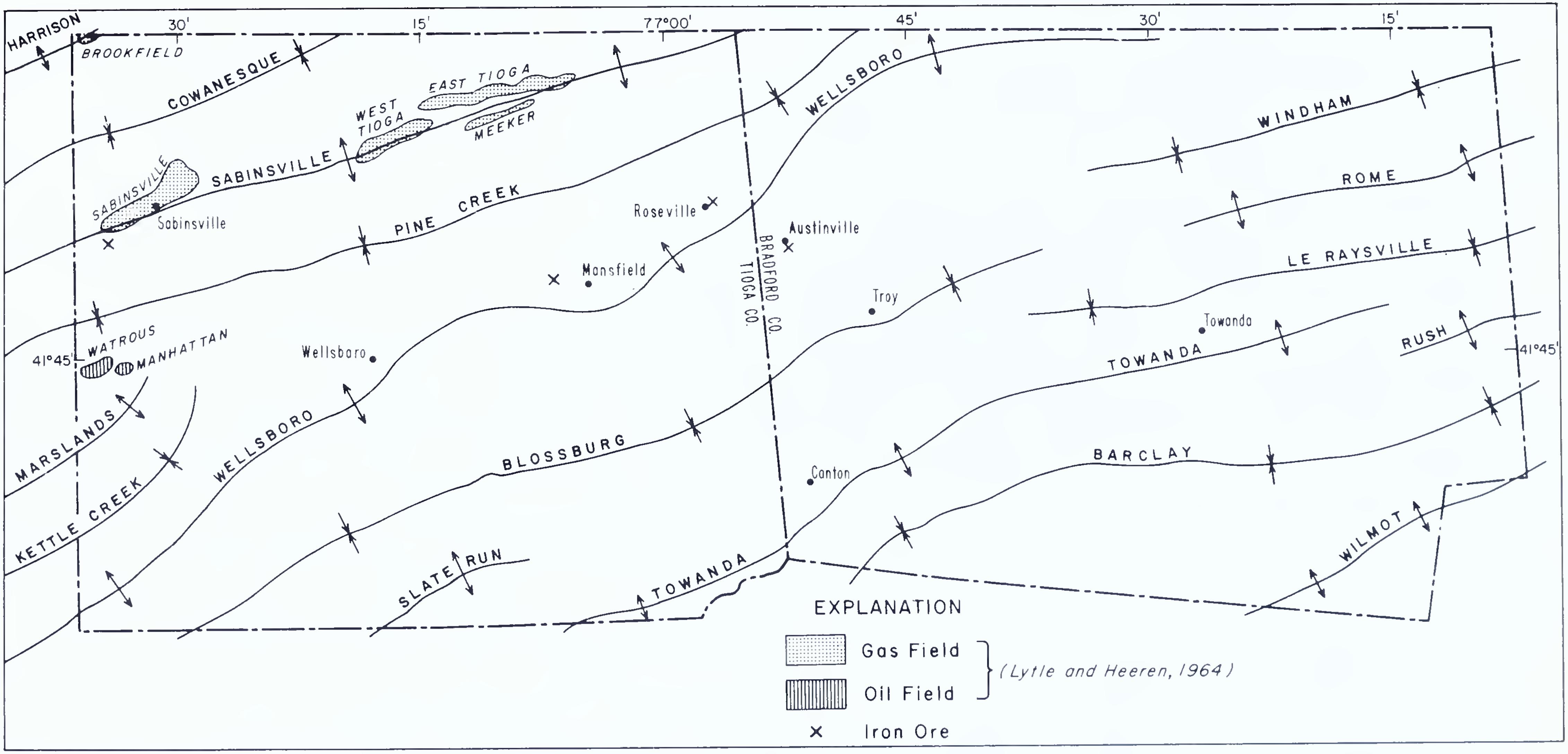


Figure 18 Locations of structural axes, oil and gas fields, and mined iron ore bodies in Tioga and Bradford Counties, Pennsylvania

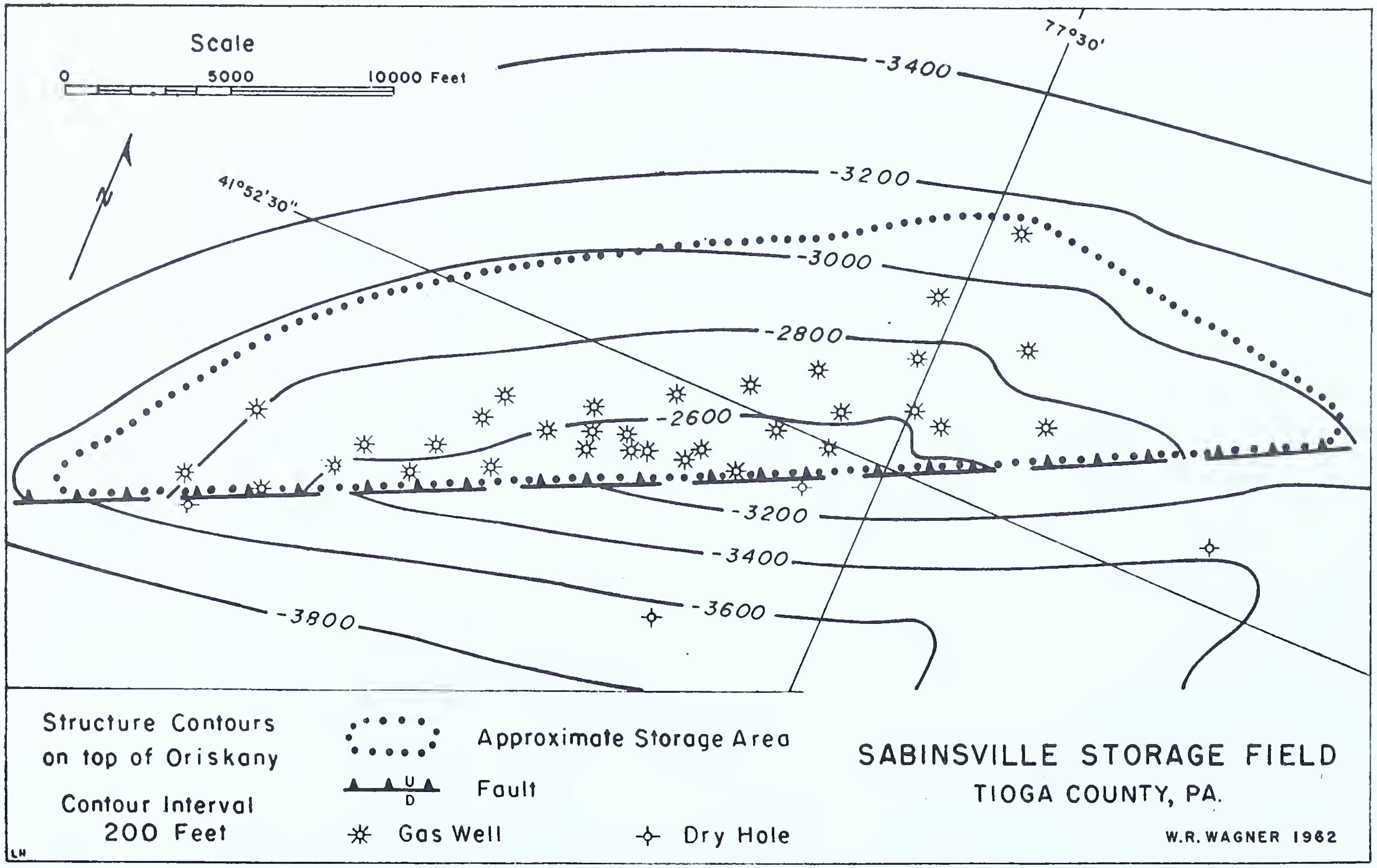


Figure 19. Structure contour map of the Sabinsville storage field, Tioga County, Pennsylvania (from Lytle, 1963, Plate 12).

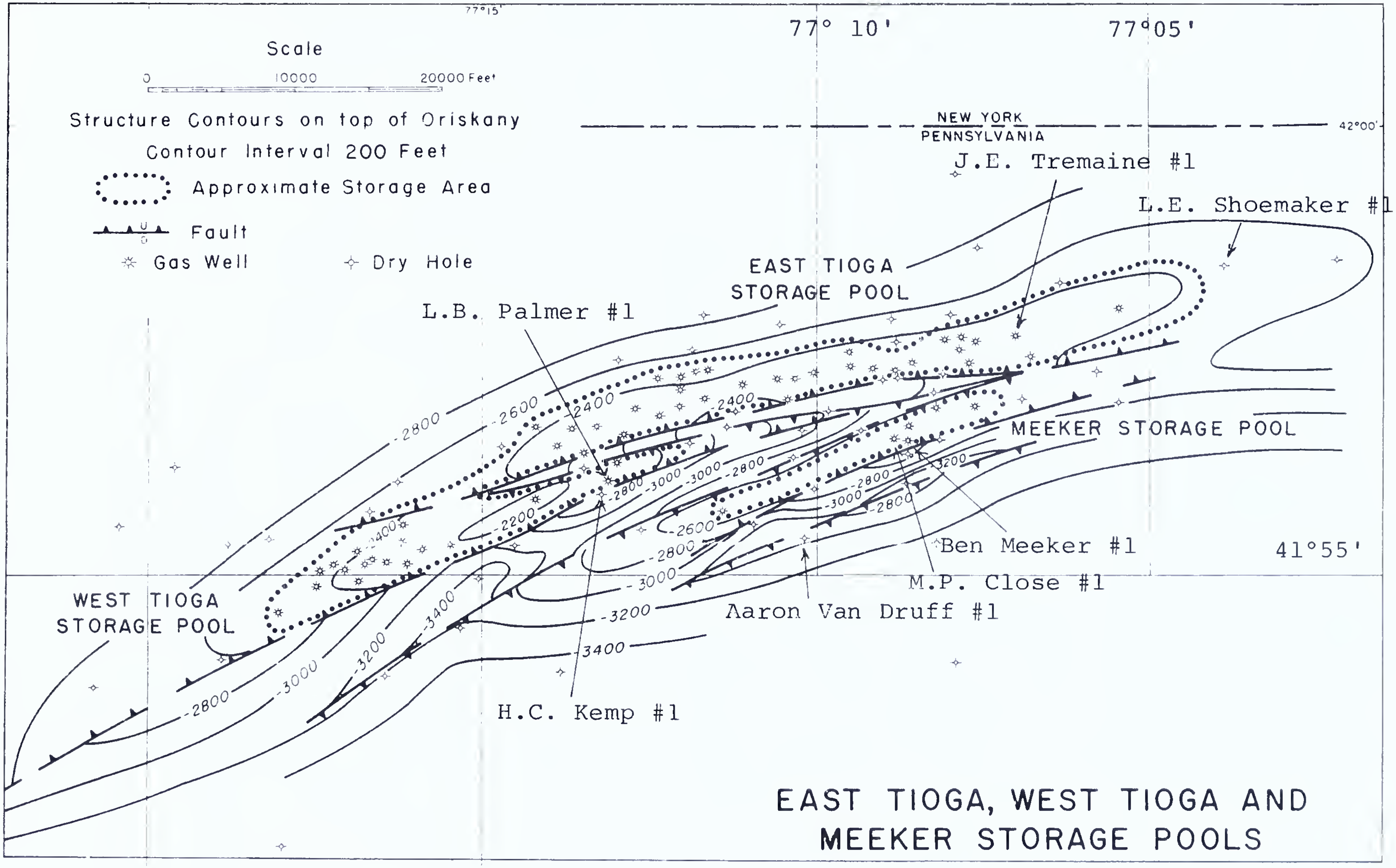


Figure 20. Structure contour map of the East Tioga, West Tioga, and Meeker storage pools in the Tioga Field, Tioga County, Pennsylvania (modified from Lytle, 1963, Plate 14).

structure. Cathcart and Myers (1934) show in their cross sections that the Meeker pool is bounded on the north and south by a pair of reverse faults which dip steeply northward (i.e., underthrusts which create a local anticline). This structure, caught as if it were in a pincers, could explain why the Meaker #1 came in at 73,000 MCF and R.P. 1530 psi and the M.P. Close #1 at 70,000 MCF and R.P. 1500 psi (Fettke, 1950) just as well as the formation of another anticline just south of the main anticlinal axis. If the faulting is imbricate thrusting, as postulated by Gwinn (1964) and Murphy (1981), then the Meeker and Close wells should have been farther north up dip. Some wells crossing faults, such as H. C. Kemp #1, found greater displacement at the Oriskany horizon than the Tully horizon (Cathcart and Meyers, 1934).

Table 2, extracted from Fettke (1950), shows all the wells that reached the Salina.

Table 2. Selected logs of producing wells and Salina tests (from Fettke, 1950).

	L.B. Palmer #1	Ben Meeker #1	M.P. Close #1	L.E. Shoemaker #1	J.E. Tremaine #1	H.C. Kemp #1	Aaron Van Druff #1
Elevation	1764	1677	1634	1474	1005	1712	1686
Tully	3015-3100	3200-3265	3130-3225	2909-2991	2310-2374	3083-	3629-3700
Oriskany	4005-	4197-	4134-	3930-3980	3355-	4350-4434	4629-4670
Salina				4261 Syracuse salt mbr. 4424-6508	Salt 3955-	4830- Salt 5200-5375	Salt 5128 5154
Total Depth	4012	4203	4136	7148	3980	5375	5154

The L. E. Shoemaker #1 shows an anomolously thick sequence. The detailed log, run by C. R. Fettke, is in Cathcart and Myers (1934, p. 9-14). It shows the Camillus Formation starting with anhydrite at 4261 ft and going down to 6530 ft. The Vernon Shale occurred at 6530-7148 ft with anhydrite at 7060 ft.

The West Tioga and Meeker pools are currently used for gas storage by North Penn Gas Company. New York State Natural Gas Company uses the East

Tioga and Sabinsville pools similarly (Lytle, 1963).

Fettke (1950) listed 9 wells drilled in Bradford County between 1931 and 1934. Two had shows of gas from above the Oriskany and were abandoned. Fettke (1956) lists 2 more, 1 with a show. Lytle and others (1961) has one well located 6000 ft south of lat. 42°00'N, and 2650 ft west of long. 76°40'W. The Anna Carber #1 entered the Salina at 4840 ft and had a total depth of 7220 ft. The Salina thickness of 2380 ft is as anomolous as the L. E. Shoemaker #1 thickness of 2887 ft.

METALLICS

Iron Ore

The first iron furnace was built in Blossburg in 1825 (Anon., 1883, 1897). The ore used was siderite ball ore associated with the coal. An analysis from Bear Creek Hill, Blossburg (Rogers, 1858) shows carbonate of iron 44.79 percent, peroxide of iron 8.41 percent, and metallic iron as 27.05/100 parts.

Lesley (1859) lists a hot-blast charcoal furnace at Blossburg as being built in 1841 but in extreme disrepair. He also lists the Mansfield stream hot-blast charcoal furnace built in 1854. It is described by Lesley (1859, p. 94) as "10 feet across the base by 33 feet high, and made in twenty-one weeks of 1856 about 600 tons of metal out of a peculiar fossiliferous ore from three miles west, on the rolling country of Formation VIII three or four hundred feet above the river on the road to Wellsborough." This is the "Mansfield" ore.

The Upper, First or Mansfield ore bed is described by Sherwood (1878) as 2 or 3 ft thick and very gently dipping to the northwest. Sherwood says that the bed: "is not characterized by the <u>fish remains occurring in the lower beds</u>. Its fossils consist mainly of <u>Spirifer and Productus</u>." (1878, p. 60).

He describes the Middle or Second bed as being 200 to 400 ft below the upper bed containing fish remains and he presumes it to be representative of the Roseville and Austinville ore.

The Lower or Third bed he found in the bed of the Tioga River. Sherwood (1878, p. 61) says, "Five to ten inches remain, of more than ordinary quality, but <u>containing small flattened pebbles of quartz</u>."

Analyses of the ores by McCreath (1879) (Table 3) show an eastward reduction in iron content. Mansfield and Roseville ores were smelted at Mansfield (Plate 2, C). Austinville ore was taken to Elmira, New York. The remaining 3 ores were never mined.

Sherwood refers to the Second bed as having a peculiar seedy structure (probably oolitic) and being similar to the Clinton ore. The "Mansfield" ore, (Stop 9, Day 2) is also oolitic.

A

B

C

PLATE 2

Table 3. Iron ore analyses arranged from west to east starting with the Mansfield ore bed. (From McCreath, 1879)

	Analysis Number	Bed	Fe	S	P	Residue
Mansfield Ore Bed	(198)	1st	38.9	0.063	0.603	11.565
Roseville Ore Bed	(200)	2nd	41.9	0.035	0.389	28.950
Tioga River	(335)	3rd	43.1	0.018	0.657	20.901
Austinville Ore Bed	(333)	2nd	33.6	0.018	0.179	40.690
East Troy	(332)		24.7	0.016	0.248	52.440
LeRoy, Gulf Brook	(331)		20.7	tr.	0.185	46.655

Several prospects, outcrops, and mines have been located and sampled (Locations determined from Sherwood, 1878, and Walker & Jewett, 1875). Specimens of both Upper and Second beds are very similar and are not easily distinguished from the Clinton ore. Detailed thin-section analyses along with detailed field work are necessary to verify if there are actually 3 ore veins. This work will be started this fall (1981) along with completion of the mapping of the Austinville mine.

Copper

Rogers (1858) reports a small amount of malachite 9 miles below Monroe Corners on the Berwick Turnpike. Heverly (1924) reports traces of copper in Overton and Terry townships. A sufficient quantity of ore in Albany township justified opening a mine in 1853. Tests of the ore made in 1900 and 1908 apparently indicated an excellent ore, but too expensive to mine.

Humphreys and Friedman (1981, Figure 1) found local concentrations of malachite at their uranium sampling sites.

Uranium

Local concentrations of uranium occur in rocks of the Catskill Formation near New Albany in southern Bradford County (McCauley, 1961; Klemic, 1962; Rose, 1970; and Humphreys and Friedman, 1981). The concentrations are small, generallv only a few ppm, and are not presently of economic value.

Plate 2. A. Inclined plane at the Pine Creek clay mine, was used unsuccessfully to slide clay down to Pine Creek. Photograph loaned by Mr. Elwyn S. Lewis.

B. Aerial tramway used to transport coal at Antrim, Pennsylvania. Photograph loaned by Mr. Gale P. Largey.

C. Pig iron works at Mansfield, Pennsylvania, about 1879. Then known as "Smokey Row," the site was located on what is now Brooklyn Street. Newspaper photograph loaned by Mr. George C. Broden.

COAL

Introduction

Bradford and Tioga Counties contain 3 of the 6 small coal fields in this part of Pennsylvania which are known collectively as the North-central Fields. The Tioga County fields are Blossburg-Antrim and Gaines (or Gurney), while Barclay is the Bradford County Field.

The coal of Tioga County is mostly medium volatile bituminous rank with coal analyzing on a dry, ash-free basis between 68 and 78 percent fixed carbon (These and other percentages which follow differ slightly from older published data presented in Table 4, and may reflect differences in analytical techniques.) Coal from the Gaines Field is expected to average about 70 percent fixed carbon, while that from the Blossburg-Antrim Field is probably between 75 and 78 percent fixed carbon.

Table 4. Coal analyses for Tioga and Bradford Counties arranged from east to west (from McCreath, 1879).

	Coal	Analysis #	Water %	Volatile Matter	Fixed Carbon %	Sulphur %	Ash %
Barclay Basin							
Falls Creek	A	659	0.850	16.625	67.293	0.498	14.735
Barclay (Ave.)	B	663	0.770	17.110	70.744	0.775	10.600
Blossburg Basin							
Fall Brook (Ave.)	B	657a	1.050	18.540	69.934	0.661	9.815
Morris Run	B	664	1.120	18.570	72.097	0.583	7.630
Arnot	D	669	1.180	21.586	71.574	0.907	4.753
Antrim	B	671	2.260	20.240	71.847	0.548	5.105
Bache Mine	B	706	2.240	20.045	70.357	0.588	6.770
Gaines Basin							
Knox & Billings	B?	703	3.260*	27.860	61.421	0.804	7.655
W. Br. Pine Cr. (Potter Co.)		704a	3.070*	30.970	55.140	0.975	9.845
			*soaked in transit				

The coal of the Barclay Field in Bradford County is low volatile bituminous rank with the average dry, ash-free analysis being about 80 percent fixed carbon.

The Bloss or "B" coal complex is the most important in the North-central Fields. The Bloss is a closely related collection of 1 to 3 beds separated by up to several feet of shale or underclay. In the Barclay Field the lower bench may be separated by up to 20 ft. The Bloss usually has a sulfur content between 0.4 and 2.0 percent (as received basis), occasionally ranging up to 3.0 percent. Ash content is between 6 and 18 percent. As a closely associated collection of seams, the Bloss complex appears to be widely persistent across much of the area, although individual beds may not be

continuous.

The name "Morgan" seems to be applied to two or more coals which occur at more or less the same stratigraphic position, 30 to 60 ft above the Bloss. None of the beds in this interval is completely persistant, but 1 to 2 are usually present. Sulfur content in these seams ranges from 0.7 to 1.8 percent sulfur and 10 to 25 percent ash (as received basis).

The Seymore coal is largely confined to the central part of the Blossburg-Antrim Field. Within that limited area it seems relatively persistent. The few analyses available show the Seymore to be between 2.5 and 3.0 percent sulfur and 6 to 9 percent ash (as received), but may be considerably more variable than that.

Barclay Coal Basin

Coal was discovered in 1812 by Abner Carr while hunting (Craft, 1878; Bradsby, 1891, p. 24). Bradsby (1891, p. 432) gives his name as Edsal Carr and Heverly (1924) calls him Absalom Carr. The coal was found on lands owned by Robert Barclay of London, England, hence the name (Craft, 1878).

Initially the coal was brought out on sleds, but soon roads were built to the Mason and Cash mines to better supply the blacksmiths of northern Pennsylvania and southern New York (Heverly, 1924). This was the amount of development between 1812 and 1856. The North Branch Canal, which was started in 1836 and stopped repeatedly due to funding problems, was completed in 1854. In 1853 the Barclay Railroad & Coal Company and the Schraeder Land Company were formed. The common owners bought the Barclay lands and built a railroad, 16 miles long, up Schrader Creek from the canal basin in Towanda to the Foot of the Plane where an inclined plane rose 475 ft in 1/2 mile (Craft, 1878). It was completed in the fall of 1856 and there was a small tonnage shipped. Development of the basin can best be seen in the production statistics taken from Craft (1878, p. 120) (Table 5). The total production soon after 1868 was used by the railroads. The Barclay coal mines were abandoned December 31, 1880 (Heverly, 1924).

Blossburg Coal Basin

The Blossburg coal was discovered in 1792 by the Patterson brothers. Aaron Bloss bought the land in 1806 and opened up the coal for his own use. The same year David Clemmons (Clemons) came to the area and whether or not he opened his mine on Bear Creek that year is unknown. Clemons mined the fifth vein from the surface. Soon after his mining began, Aaron Bloss opened up the sixth vein from the surface, known as the "Bloss" vein (Anon. 1883, 1897).

The Arbon Coal Company was formed in 1834 and the railroad from Blossburg to Corning was completed in 1840. Between 1840 and 1843 the Arbon Coal Co. shipped 49,633 tons. The W. M. Mallory & Co. then formed and from 1844 to 1857 shipped another 405,116 tons. Duncan A. Magee took over from Mallory and shipped 78.996 tons making a total output of 533,745 tons from 1840 to 1859 at which time mining ceased.

Table 5. Annual production (in tons) of the coal mines of Bradford County (Craft, 1878).

	Barclay Coal Co.	Fall Creek Coal Co.	Towanda Coal Co.	Schraeder Coal Co.	Total Production (Net Tons)
1856	2,295	....	....	....	2,295
1857	6,265	....	....	....	6,265
1858	17,560	....	....	....	17,560
1859	30,143	....	....	....	30,143
1860	27,718	....	....	....	27,718
1861	40,835	....	....	....	40,835
1862	52,779	....	....	....	52,779
1863	54,535	....	....	....	54,535
1864	62,058	....	....	....	62,058
1865	48,375	16,936	7,886	....	73,197
1866	37,968	29,604	31,881	....	99,453
1867	30,119	16,952	27,668	....	74,739
1868	......	6,595	67,080	....	73,675
1869	......	4,303	176,307	....	180,610
1870	......	77,025	196,310	....	273,335
1871	......	129,095	249,240	....	378,335
1872	......	118,882	263,960	....	382,842
1873	......	85,315	252,329	....	337,644
1874	......	21,281	215,572	100,219	337,072
1875	......	18,527	200,424	157,686	376,637
1876	......	....	183,992	200,795	384,787
	410,650	524,515	1,872,649	458,700	3,266,514

The Tioga Improvement Company opened mines at Morris Run and built a railroad to them in 1852. From 1853 to 1863 they shipped 323,174 tons. They leased to the Salt Company of Onondaga which shipped 267,809 tons from 1863 to 1866. The Morris Run Coal Co. then took over and was followed by the Morris Run Coal Mining Co. in 1872. They mined 4,513,120 tons up to January 1, 1881. Production for the year 1881 was 375,000 tons making a total of about 5,480,000 tons since 1853 (Anon., 1883, 1897).

At Morris Run the Jones mine was ventilated by a 20-foot, steam-driven exhaust fan and coal was hauled to the chutes by mine cars on an endless cable. The "New" mine used ventilating shafts and mules for hauling to the main drift where mine locomotives took it to the chutes. During 1894, 522 miners, out of 709 employees, produced 209,861 tons working an average of 138 3/4 days (Anon., 1897).

The Fall Brook Coal Company organized in 1859 and shipped a few tons. From 1859 to 1873 they shipped about 2,700,000 tons. In 1873 they opened up the mines in Antrim and consolidated the weight bills. Between 1859 and January 1, 1882, they shipped a total of 4,629,877 tons.

The Blossburg Coal Co. opened up Arnot in 1866. From 1866 through 1881 total tonnage mined was 3,181, 193 tons. Approximately 13,290,000 tons had been removed by 1882, excluding local mines (Anon., 1883). The Bear Run

coal mines at Landrus opened in 1888. It was an electric mine with 30 hp motors hauling the cars from drift to chute. They could produce 625 tons/day (Anon., 1897).

To the west of Antrim several openings were made, probably in the late 1870's, and the coal was hauled out on sleds over the top to Wellsboro. These mines were 30 to 40 ft higher than the Antrim mines. From 1903 to 1937 an aerial bucket tram with an 1100 lb. bucket crossed the valley to carry the coal to the railroad (Plate 2, B) (Gale Largey, pers. comm.).

Additional statistics (Anon., 1897) show that 1,769 miners produced 789,414 tons in 1895. The maximum producing year was 1873 with 991,057 tons and nearly 25,000,000 tons had been produced since 1840. Coal sold in the western gold camps at $25.00 a gunny-sack. In 1880 the Blossburg Coal Co. erected 200 beehive coke ovens at Arnot. Production in 1895 was 976 tons. In 1881 they made 56,000 tons of coke (Anon., 1883).

The historic highlight of the Blossburg Coal Basin was the visit in 1841 by Sir Charles Lyell. His published account on his return to England is worth quoting in part (Anon., 1897, p. 126), "It was the first time I had seen true coal in America, and I was very much struck with its surprising analogy in mineral and fossil character to that of Europe:" An extensive stratigraphic comparison is then made and the statement ends, "The agreement of these phenomena with those of the Welsh coal measures 3,000 miles distant, surprised me, and led me to conclusions respecting the origin of coal from plants not drifted, but growing on the spot, to which I shall refer hereafter."

Gaines Coal Basin

The Gaines Coal and Coke Company started mining in March, 1883, at Gurnee (Anon., 1897). The coal extends westward into Potter County, but occurs in only the highest hill tops. Their mines were opened on the Knox & Billings coal which had been worked locally earlier. Many years prior to this a higher vein, the Third, had been worked (Platt, 1878). After employing about 100 men in the early years, the operation rapidly declined. In 1895 a total of 16 men mined 6,511 tons, and the coal was expected to run out shortly (Anon., 1897).

Modern Production

Present day stripping operations are being carried out by the Jones & Brague Mining Co. and the Antrim Mining Co.

The Antrim Mining Co. is working west of Wilson Creek and Pennsylvania Route 287, the westernmost area of the basin. They ship an average of 1200 tons/day to New York State Electric & Gas power plants located at Bainbridge, Dresden, Johnson City, and Painted Post (Neil Hedrick, Antrim Mining, pers. comm.).

The Jones & Brague operations are at Morris Run (Pine Hill section), Fall Brook, and Barclay. Estimated reserves in the Barclay Basin are for 10 to 15 years, and combined Fall Brook and Pine Hill is 3 years. They will

start in the Arnot area this fall where they estimate 2-3 million tons are present. They are taking the "Bloss" vein at Barclay and both the "Morgan" and "Cannel" at Fall Brook-Pine Hill. They are shipping 2200 tons/day (100 tons from Barclay) to the same four power plants previously mentioned. Yearly production showed steady growth from 1961 (194,648 tons) up to 1971 (856,605 tons). From 1972 through 1980 production has fluctuated and has averaged 663,212 tons (Robert Jones, pers. comm.).

Total production from Tioga County, mostly from the Blossburg-Antrim Field, was approximately 70,000,000 tons up to January 1, 1980. Production from Bradford County's Barclay Field was approximately 10,000,000 tons up to January 1, 1980.

Estimated remaining in-place coal resources over 24 in. thick for Tioga County are between 30 and 55 million tons depending upon the source of the estimate. Estimates of in-place coal resources over 24 in. thick for Bradford County are between 12 and 25 million tons.

NONMETALLICS

Stone

Numerous quarries have been opened in both counties. Flagstone and building stone were produced. A small flagstone quarry in sandstones of the Huntley Mountain Formation is passed along the route between Stop 3 and Lunch on Day 1 (Mileage 64.4). The present Tioga County courthouse was started in 1835 and made from local sandstone (Anon., 1897). This sandstone probably came from the quarry located northeast of Antrim on Rock Run. About 1 1/2 miles north of this quarry another was opened to supply the riprap along the Tioga River at Mansfield. This quarry, located at Brownlee, has been backfilled and seeded, but the stone appears identical to that used for the courthouse. Further information on flagstones in Bradford County is available in Glaeser (1969).

McCreath (1879) has two "Chemung" limestone analyses of interest (Table 6). Analysis 336 came from a quarry 1 1/2 miles north of Mansfield and was used as flux in the iron furnace (Sherwood, 1878). Analysis 334 is from Klines quarry (Stop 1, Day 1). Sherwood (1878, p. 38) says, "Mr. Kline has recently commenced burning this limestone, selling the lime at the kiln for fifteen cents per bushel." This stone, the Luthers Mills coquinite, has more recently been used as riprap for flood protection. Some examples of its use can be seen along U. S. Route 6 near Stop 1.

Clay

Clay in Tioga County is found in the glacial deposits and in association with the coal-bearing sequence. In Osceola, Robert Tribbs started brick making, and built the first brick house in Tioga County in 1829. An Andrew Bossard made brick at his yard in the swamp (Anon., 1883). Presumably, these were glacial clays.

At the turn of the century, a fireclay mine was opened on the east side

Table 6. Limestone analyses from McCreath (1879).

	Tioga County (336) Wilson	Bradford County (334) Kline
Lime	28.872	41.048
Magnesia	1.117	1.135
Sesquioxide of iron	2.142	4.428
Alumina	2.269	2.613
Sulphuric acid	0.087	0.167
Phosphoric acid	0.729	0.279
Carbonic acid	23.227	33.240
Insoluble residue	41.700	18.010
	100.143	100.920

of Pine Creek (Plate 1, B). It is located about 2 1/2 miles north of Blackwell on Clay Mine Road. Mr. Elwyn Lewis (per. comm.) says that the mine had a one foot coal seam. The clay was dumped down to Pine Creek on an inclined plane (Plate 2, A). The first incline, which did not work, was lined with steel plate. It was then lined with glass 1 1/2 in. thick, but that didn't work either. They then resorted to a bucket train. The company had a contract with a Buffalo area brickyard but none with the railroad and went bankrupt about 1910.

The Lodge on the Green motel in Painted Post, N.Y., built about 1964, is made of hand mand brick. The brickyard in Elmira, New York, used clay taken from under a coal seam opened by Jones and Brague (Robert Jones, pers. comm.).

Glass and Molding Sand

Glass factories were established in Blossburg (1847) and Covington (1850) (Anon., 1883, 1897). Their sand probably came from completely weathered conglomerate located between the forks of Carpenter Run south of Blossburg (Rogers, 1858, vol. II). Window glass was shipped to Detroit, Milwaukee, and Galveston (Anon., 1883). The sand occurrence is similar to Sherwood's (1878) description of "the sand-bed barrens" west of Niles Valley where the sandstone had disintegrated to pure white sand. This locality was possibly the sand source for the Wellsboro glass factory which opened in 1886 (Anon., 1897). These sands probably were the molding sands for the local foundries, but there is no reference to this.

In 1888 the Antrim Sand Co. opened a quarry at Brownlee with a crusher to supply glass sand to Corning and traction sand to the railroads (Anon., 1897).

Recently, Warwick Silica has reopened the former Telequartz quarry north of Morris; they are quarrying the basal Pottsville quartzitic sandstone and conglomeratic sandstone. The material being quarried is

identical to the basal Pottsville seen at the Lunch Stop, Day 1 of this Field Conference. Warwick is equipped to crush and wash 800 tons/day. Their sand is sold to several foundries and glass plants, and is shipped as far as Latrobe (Fred Wade, pers. comm.). Some of the sand product has been used in the hydrofracturing of oil or gas wells. The silica potential of Tioga and Bradford Counties may be considerable, and detailed mapping and analysis of the basal Pottsville should be carried out.

Miscellania

Mrs. Allen W. Howland (pers. comm.) reported that a potash mine was opened during World War I on the hill south of Westfield and east of Mill Creek.

Mrs. Howland also reported that even though Bradford oil collected a premium, the Watrous oil collected one on top of that. During World War II, her father filled diesel trucks straight from the well.

ADDENDUM

Analyses (as received) of Bloss Coal at Anna S. Mine
sampled by W. E. Edmunds and T. M. Berg
Analyzed by Indiana Analytical Laboratories, Inc.

	Interval above base of coal (feet)	0.4-1.9	1.9-2.2	2.2-2.7	2.7-3.35	3.4-4.1
Proximate %	Moisture	2.6	1.0	2.0	2.7	2.1
	Volatile Matter	20.2	15.6	21.0	19.4	21.2
	Fixed Carbon	66.8	53.2	71.5	73.8	70.4
	Ash	10.4	30.2	5.5	4.1	6.3
Ultimate %	Hydrogen	4.42	3.43	4.49	4.51	4.56
	Carbon	77.0	60.3	82.4	83.4	81.2
	Nitrogen	1.19	0.80	1.28	1.24	1.20
	Oxygen	3.77	3.81	3.75	3.20	2.15
	Sulphur	0.65	0.48	0.68	0.88	2.44
	Chlorine	0.0	0.0	0.0	0.0	0.0
	B.T.U.	13,510	10,410	14,440	14,600	13,490
	Softening Temp., °F	2732+	2732+	2732+	2026	2732+
	Free-swelling index	8.0	1.0	8.5	5.5	8.0

GROUND WATER AND SURFACE WATER

by
W. D. Sevon

Water supplies in Tioga and Bradford Counties are relatively abundant and are derived from wells drilled into the Catskill and Lock Haven Formations, Pleistocene sands and gravels in numerous valley bottoms, and impoundments of streams. Wells are generally less than 100 m in depth. Water quality is good.

Yields are generally greatest from wells drilled into the Pleistocene sands and gravels; yields over 350 gpm are known from these materials. Many of the larger valleys in the area have sand and gravel fill up to 30 m or more thick, and thus form large reservoirs of readily available water. The ground water table in these valley bottoms is usually close to the surface and well depths are small. Casing of the wells and proper screening is necessary in these wells. The true potential of water yield for these deposits has not been studied, but it appears to be large.

Wells drilled into bedrock generally give lower yields than those drilled into Pleistocene valley fills. However, yields greater than 100 gpm do occur and placing of wells on fracture traces would probably substantially increase yields from bedrock in this area. Water quality from bedrock wells is generally good although some wells drilled into the Lock Haven Formation contain sodium chloride. The Lock Haven is also an occasional source of hydrogen sulphide and natural gas. Where natural gas is suspected, proper venting of wells and storage tanks is important.

Additional information on the groundwater of Tioga and Bradford Counties is available in Lohman (1939). The Pennsylvania Geological Survey in cooperation with the Susquehanna River Basin Commission is currently doing investigations on the ground water of the area. Research on the effects of strip mining on water quality has been done in the area of this Field Conference. Reports documenting some of this work include: Kantz and Associates (1976), Reed (1980), and Ward (1981).

Surface water is also relatively abundant in the 2 counties and, on occasion of excessive rainfall, is the source of flooding. Intense rainfall, both local and regional, is not uncommon in north-central Pennsylvania and damage by floods has been repetitious, particularly along the Tioga Creek drainage, both in Pennsylvania and in New York. The Tioga-Hammond (Stop 12) and Cowanesque dams have been constructed to lessen the effects of excessive surface water. Normal surface water flow is adequate to supply several impoundments utilized for water supply.

TIOGA-HAMMOND FLOOD CONTROL PROJECT

by
J. Peter Wilshusen and D. Wilson*

INTRODUCTION

A project first investigated in 1938 when seven holes were drilled for a survey report on the Susquehanna River Basin, the Tioga-Hammond Dams were authorized through federal legislation in 1958 and completed in 1979 at a cost of about $200 million (Plate 3, A and B). Actual construction was begun in May 1974 and required five years to complete.

When completed, most earthfill dams have a similar appearance but, beneath the visible rock protection and grassed slopes, each embankment is designed to mesh with the geologic conditions characteristic of the site. These include the type and condition of bedrock, the type and thickness of overburden, variations in bedrock and overburden in the project area and the availability of materials with which to build the embankments. While there are common functional requirements that must be met in all dams, the specific means of solving the problems are as varied as the sites upon which the dams are constructed.

The geology at Tioga-Hammond had a profound effect on embankment design. Subsurface conditions were determined through 482 drill holes and auger borings plus 53 test pits and trenches in conjuction with extensive laboratory tests. The results of these investigations provided data for the design of the embankments and appurtenant works as well as the location of materials for embankment construction.

Dam building frequently requires relocation of highways, railroads, utilities and cemeteries as well as buildings and sometimes entire towns. The Tioga-Hammond Lakes project included relocation of 10 miles of railroad, 19 miles of highways, 10 miles of power lines, 12 miles of pipelines, 18 miles of telephone lines and 10 cemeteries.

U. S. Route 15 between Mansfield and Tioga was moved from the Tioga River valley floor to an area east of and above the project along the flank of a 2000-foot elevation ridge. During highway construction work above and dam construction work below, a major landslide occurred on the hillside involving both the highway embankment and the right abutment of Tioga Dam. The slide took place in May 1975, involving approximately 230,000 cubic yards of material.

PROJECT FUNCTION

Tioga Dam has a 280-square mile drainage area and Hammond Dam a 122-square mile drainage area. The two dams operate together through a connecting

* Gannett Fleming Corddry and Carpenter, Inc., Harrisburg, PA.

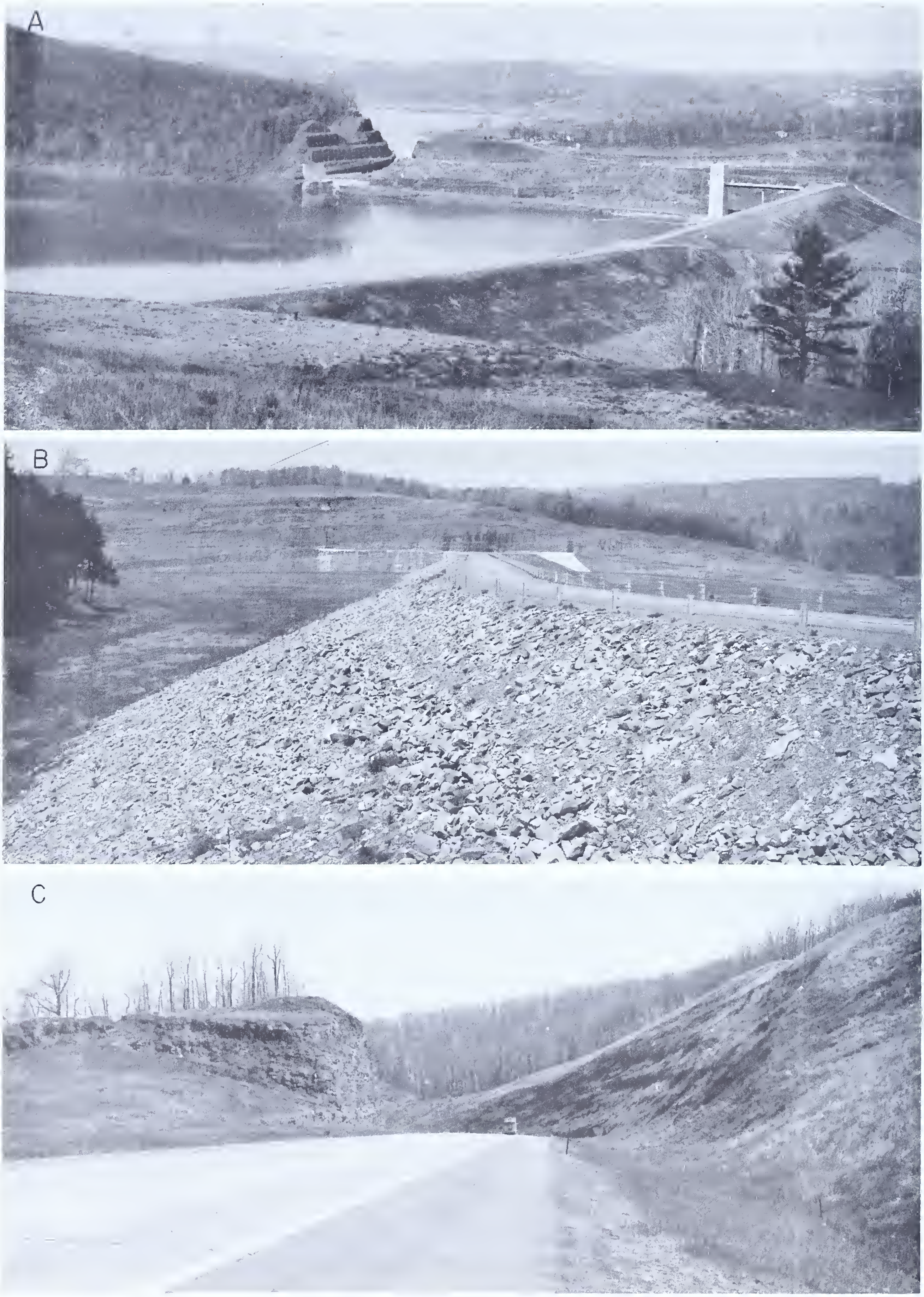


PLATE 3

channel as a single flood control project protecting communities along the Tioga, Chemung, and Susquehanna rivers. Crooked Creek valley, the site of Hammond Dam, is a broad, glacial valley with a small, meandering stream, while the Tioga River valley is narrow between Mansfield and Tioga and carries a large stream. The Tioga valley was too narrow for economical construction of a large spillway, but it nicely accomodated a large outlet works under the embankment. Conversely, the small Crooked Creek stream channel was not well adapted to a large outlet works but, the broad valley was favorable for a large spillway. The connecting channel allows the dams to share a single spillway and a single primary outlet works, resulting in an integrated project with each site used to its best advantage. There is a small outlet works through Hammond Dam to maintain minimum flow in Crooked Creek below the dam.

Under normal and low flow conditions water flowing north in Crooked Creek collects in Hammond Lake with a minimum flow being released through the small outlet works. The remainder flows east into the connecting channel through controlled gates beneath the weir crest (Stop 12-b) and mixes with Tioga River water in Tioga Lake. The latter flows north through the main gates in the Tioga Dam outlet works.

During flood periods, flow conditions are reversed. Water from the Tioga River rapidly fills Tioga Lake. Some water is released through the controlled outlet works, with the excess flowing west over the weir crest in the connecting channel to be stored in the broad Crooked Creek valley. When valley storage is exhausted, the excess from both valleys can flow over the large emergency spillway adjacent to Hammond Dam. In effect, advantage has been taken of the large, glacial Crooked Creek valley with its underfit stream to store flood water runoff from both drainage basins.

The general plan of the Tioga-Hammond Dams with the route of the Field Conference from Stop 11 across the embankments to Stop 12-a and 12-b is shown in Figure 21. From the emergency spillway at the left abutment of Hammond Dam, we traverse the Hammond embankment, passing north of the valley choker moraine, pass the dam tenders' headquarters, descend to the Tioga embankment and finish at the connecting channel between the two lakes.

The dimensions of these structures are shown in the Corps of Engineers brochure enclosed in each Field Conference packet. Tioga Dam contains 4,800,000 cubic yards and Hammond Dam 7,500,000 cubic yards of rolled earth and rockfill.

Plate 3. A. Tioga Lake in the foreground with Hammond Lake in the background visible through the benched connecting channel cut. The Tioga embankment and outlet works are on the right. B. Hammond embankment. Looking west to spillway and rock exposures of Stop 11b. Valley choker moraine is in wooded area on the left. C. Road cut on U. S. Route 15 east of Tioga Dam exposing Lower Catskill Formation. After the paved roadway had been completed through this cut, material excavated from the Tioga landslide was stockpiled in it essentially filling the cut.

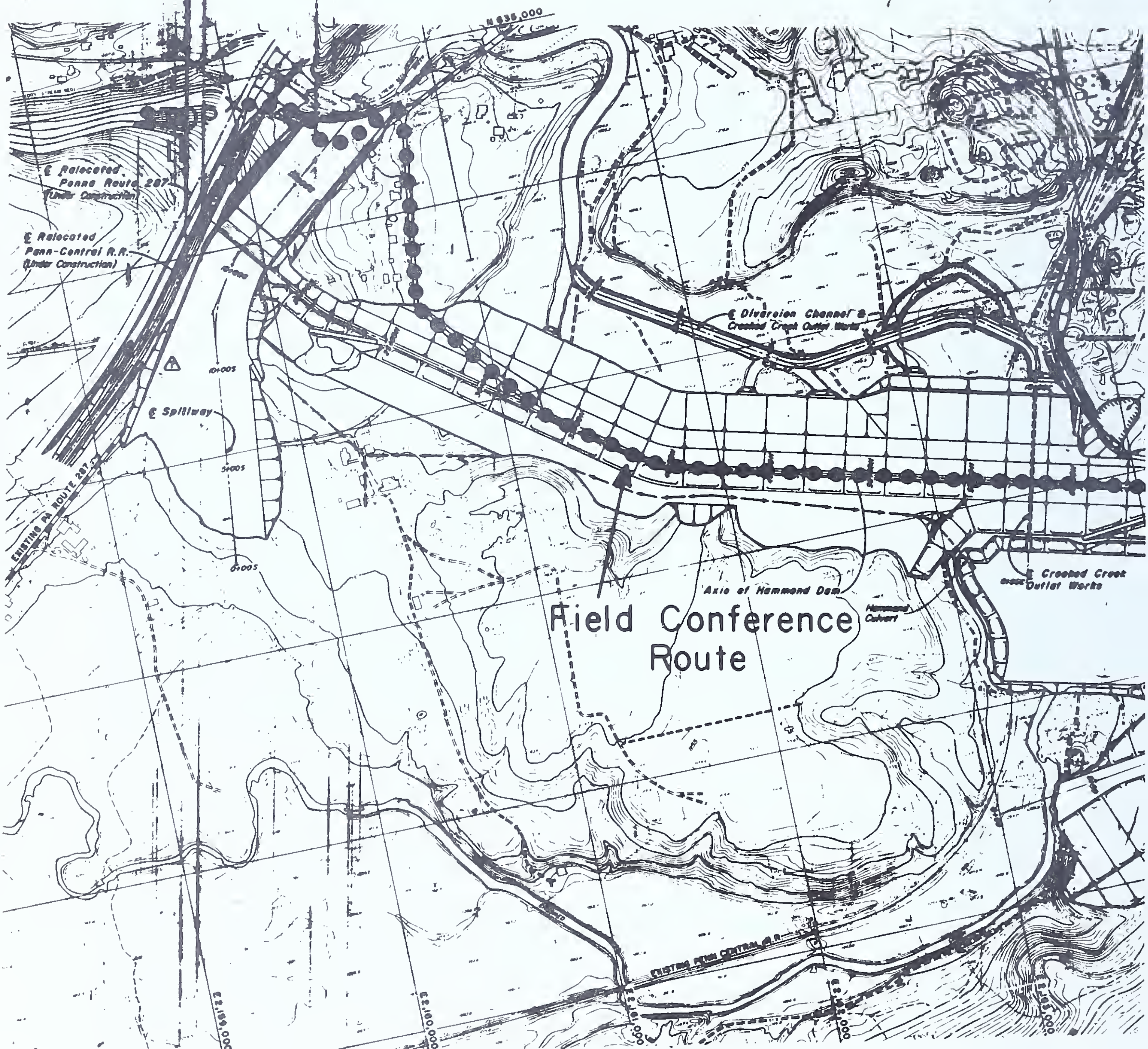


Figure 21. GENERAL PLAN

TIOGA-HAMMOND EMBANKMENTS

FOUNDATIONS AND EMBANKMENTS

An essential part of a well-designed dam is a foundation system that will limit seepage quantities to tolerable amounts, safely handle seepage that does occur, and prevent development of uplift pressures that would adversely affect embankment stability. When conditions are favorable, a cutoff trench is frequently excavated to sound bedrock directly beneath the proposed dam and the bedrock is pressure grouted through boreholes to a depth approximately equal to the height of the dam. Back-up drainage facilities are constructed, and the cutoff trench is filled with compacted impervious material above which the remainder of the embankment is constructed.

The thicknesses and distribution of glacial and fluvial material on bedrock are different at Tioga than at Hammond, the characteristics at each site dictating design criteria to be used in embankments. Overburden thickness at both sites, however, is great, reaching more than 130 ft at the right abutment of Tioga Dam and approximately 220 ft at the right abutment of Hammond Dam. These thicknesses precluded a standard cutoff trench at both sites and led to designs that would allow the large quantities of original overburden to stay in place.

At Tioga Dam (Figure 22) the bedrock surface trends uniformly, but fairly steeply, down from each side of the narrow valley beneath deposits of sand, silt, gravel, some clay, rock fragments and alluvial gravels. Overburden thickness averages 15 ft at the left abutment, 100 ft in the valley floor and 50 ft at the right abutment. Slightly downstream from the right abutment, in the area of the landslide, overburden thickness reaches 134 ft.

The abutments were excavated to rock and sealed by pressure grouting through a 4-line grout curtain. To control seepage through unconsolidated material in the valley floor an impervious core of unusual configuration was constructed (Figure 23). It extends as a horizontal blanket from an upstream cutoff trench to the centerline of the dam and rises vertically in relatively thin dimension to the crest of the dam. The most pervious layer in the foundation is an approximately 15-ft thick layer of alluvial gravel. This is intercepted by the cutoff trench and sealed with impervious core material.

Other sections of the zoned embankment, as shown in Figure 23, are rolled rock and random earthfill to provide stability, select rock and rolled rockfill on the exterior to protect the embankment and processed sand drains. Descriptions of embankment materials are listed in Table 7. The rockfill zones and the drains prevent excessive hydrostatic pressure in the embankment and are important to stability of a flood control structure. When lake levels rise rapidly, portions of the embankment become saturated and drains prevent undue pressure in the downstream portion of the dam. This is followed by drawdown, after which the saturated embankment would be unstable if it were not drained by the rockfill.

At the Hammond Damsite (Figure 24) the bedrock surface drops gently from the spillway area at the left (north) abutment and very steeply from the right (south) abutment. Surficial material on the bedrock varies from 15 to 80 ft thick at the left abutment, 25 to 115 ft in the center of the valley,

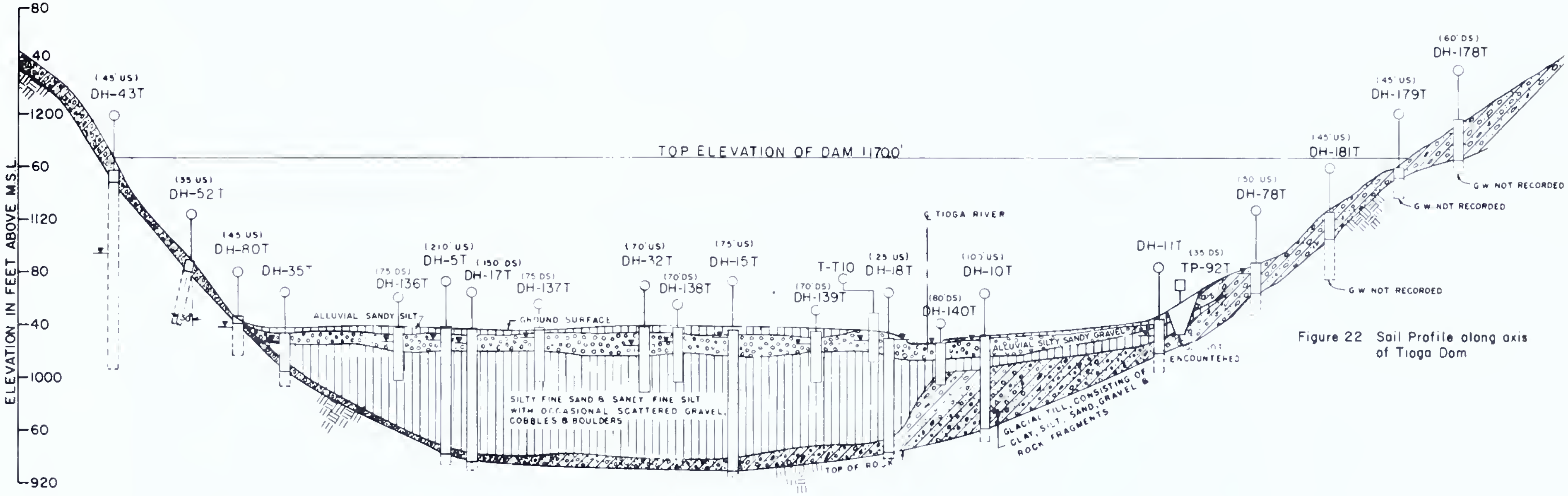


Figure 22 Soil Profile along axis of Tioga Dam

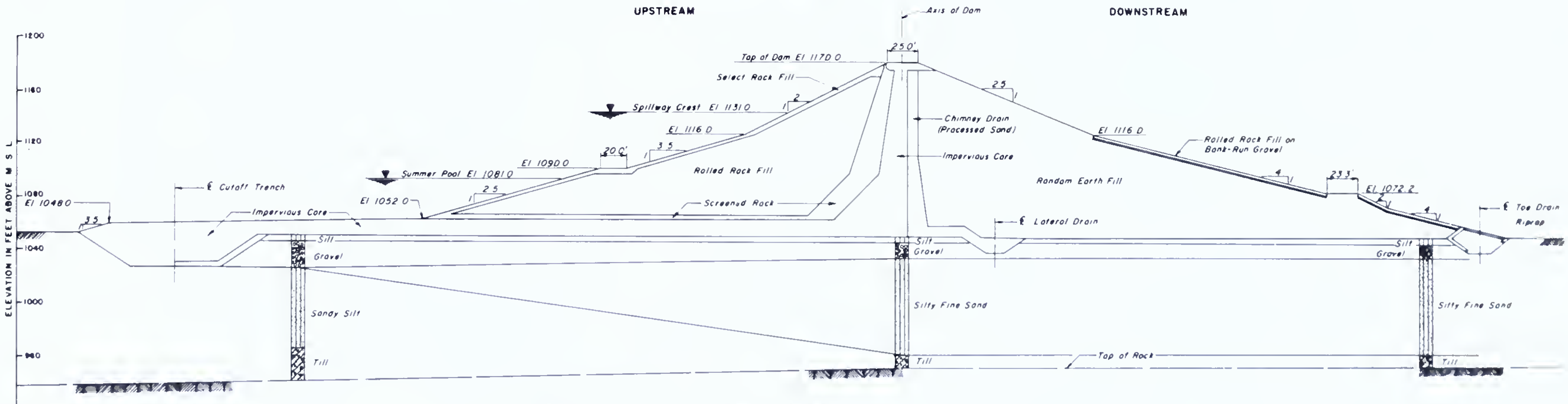


Figure 23 Tioga Dam Embankment Cross Section.

STA. 92+00T

SCALE

40 20 0 40 80

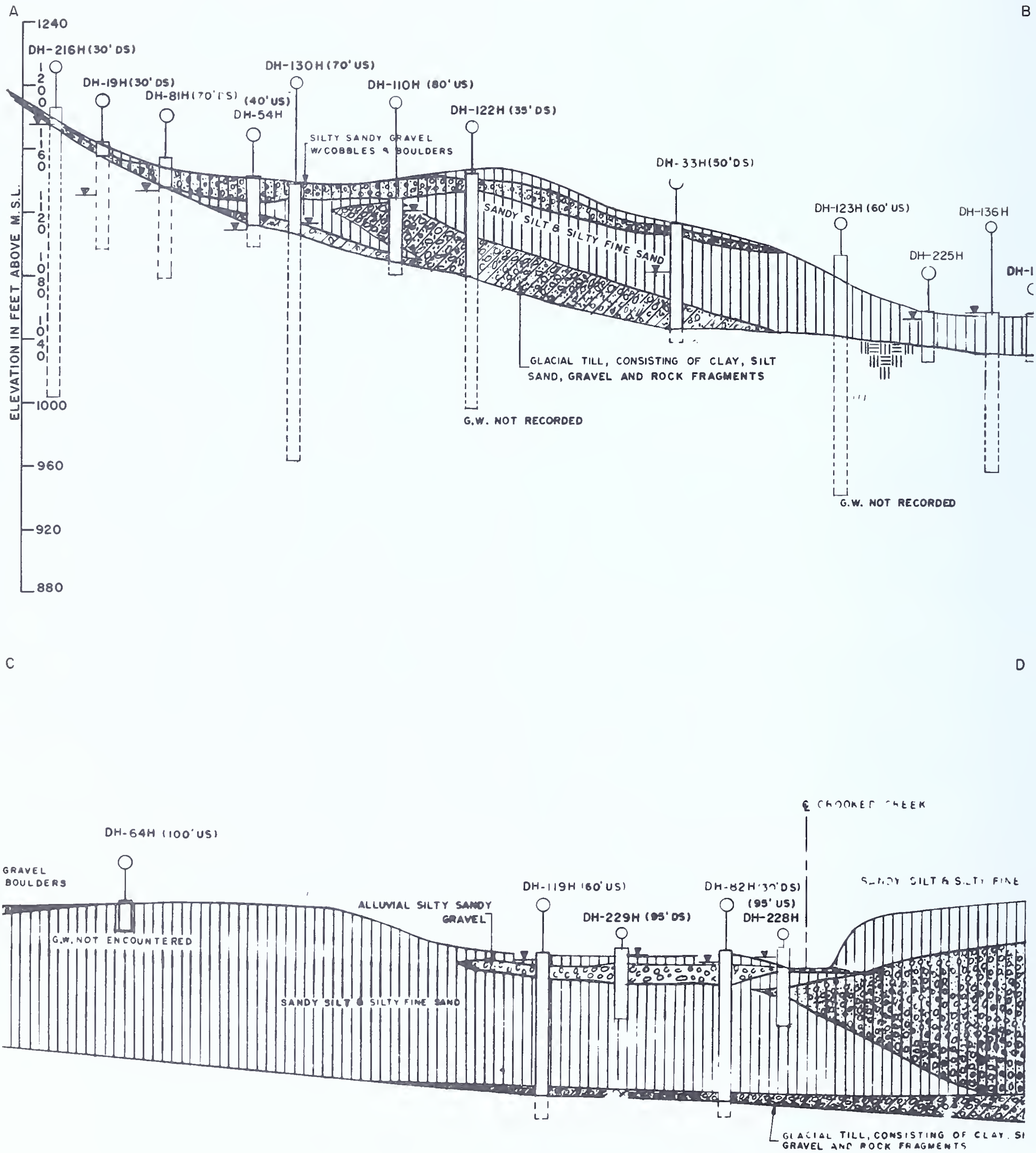


Figure 24. Soil Profile Along Axis of Hammond Dam.

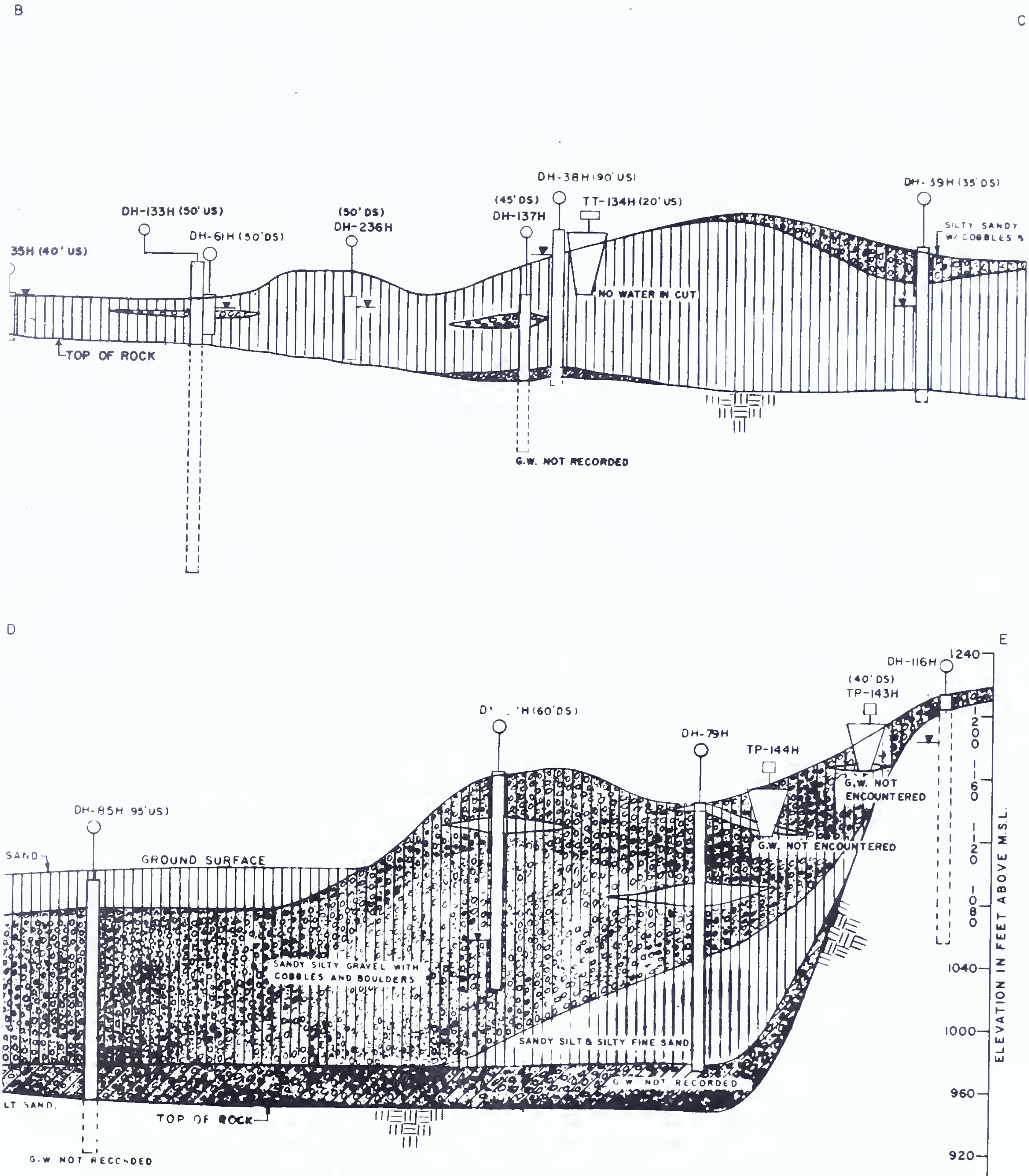


Figure 24. Continued.

TABLE 7. Descriptions of Embankment Materials Discussed in the Text

Random Earthfill

Fine silty sand and sandy silt from spillway and connecting channel excavation.

Impervious Earthfill

Sandy, silty clay containing various amounts of gravel, cobbles, boulders, and rock fragments. Impervious material for the Tioga embankment was from a borrow source in the Mill Creek Valley, 1½ miles upstream from the Tioga embankment. Impervious material for the Hammond embankment was from a borrow source west of the spillway.

Rolled Rockfill

Sandstone, thin-bedded siltstone and shale with minor amounts of limestone. Material was excavated from the connecting channel, spillway, and outlet works. Specifications called for the rock to be broken, by blasting for excavation, to generally less than 1 ft in diameter with a maximum of 2 ft and the largest dimension no more than 3 times the least dimension.

Select Rockfill

Rockfill selected within size limitations having less variation than rolled rockfill. Hard, durable sandstone.

Sand Drains

Processed sand the consistency of which is gravelly and which is specified to be well-graded, clean, and free-draining material.

and a thick 150 to 220 ft in the right abutment. The overburden is characterized by its lateral and vertical variability and appears to have accumulated at a stationary glacial ice margin. Predominant unconsolidated materials at the Hammond damsite are relatively uniform silt deposits extending from the spillway to the western edge of the Crooked Creek floodplain; relatively clean alluvial gravels overlying silts and silty sands in the floodplain; and silty sands, silty gravels, and silts extending from the eastern edge of the floodplain to the right abutment. Despite the variability of foundation conditions, the same functional requirements of seepage control and stability had to be met at all locations. Foundation conditions, material availability and economic considerations were such that three types of embankment configurations were required for Hammond Dam. Transition reaches were used to gradually change from one typical section to the next. The abutments of Hammond Dam, as at Tioga, were excavated to

rock and sealed by pressure grouting a 4-line grout curtain.

In the Crooked Creek floodplain area, where the highest section of Hammond Dam is located, conditions were similar to the conditions in Tioga valley. The general configuration of Tioga Dam, shown on Figure 23, illustrates the general concepts for this portion of Hammond Dam as well.

To the west of the floodplain area, the clean alluvial gravels pinched out along the periphery of the choker moraine and did not exist under most of the embankment between the floodplain and the spillway. In this reach the foundation was sufficiently impervious that the impervious core required no blanket segment extending upstream. A typical section through Hammond Dam in this reach is shown on Figure 25.

To the east of the floodplain area, topographic and geologic conditions led to selection of the third type of embankment section. From the eastern edge of the floodplain to the right abutment of the dam, the embankment has an inclined core instead of the vertical core configuration used elsewhere. An impervious blanket was required to minimize seepage through underlying sands and sandy gravels.

LANDSLIDE

A major landslide occurred above the right (east) abutment of the Tioga Dam in May 1975. Movement was continuous over a period of several months and was confined to glacial and colluvial material without involving bedrock. The slide area is approximately 500 ft wide and 900 ft long within which the ground moved by earthflow with rotational slumping near the top. The surface of movement was a 4 to 16 ft thick clay layer between 2 tills with a considerable amount of seepage at the clay zone.

Examination of airphotos taken in 1969 shows a depression in the valley side which may have been formed by a tributary stream. This steep, tributary valley was nearly filled with glacial and colluvial material resulting in a buried bedrock cut covered with thick unconsolidated material up to 145 ft thick. The bedrock surface configuration would tend to concentrate groundwater in the depression with circulation of flow and hydrostatic pressure affected by the clay layer.

Ground movement in this potentially unstable area was probably triggered by a combination of construction activities which involved excavation at the toe, and drainage changes and placement of fill materials at the head, as well as occurring at a time of the year (May) during which landslide activity generally increases because of increased water runoff and wet ground conditions.

To repair the slide the following was done: (1) Excavate approximately 1,167,000 cubic yards of slide material above the clay and stockpile it in the new U. S. Route 15 roadcut on the pavement north of the slide area (Plate 3, C); (2) Excavate and waste the clay layer; (3) Replace and compact stockpiled material after placing 220,000 cubic yards of rockfill from excavation in the southwest portion of the U. S. Route 15 cut and installing

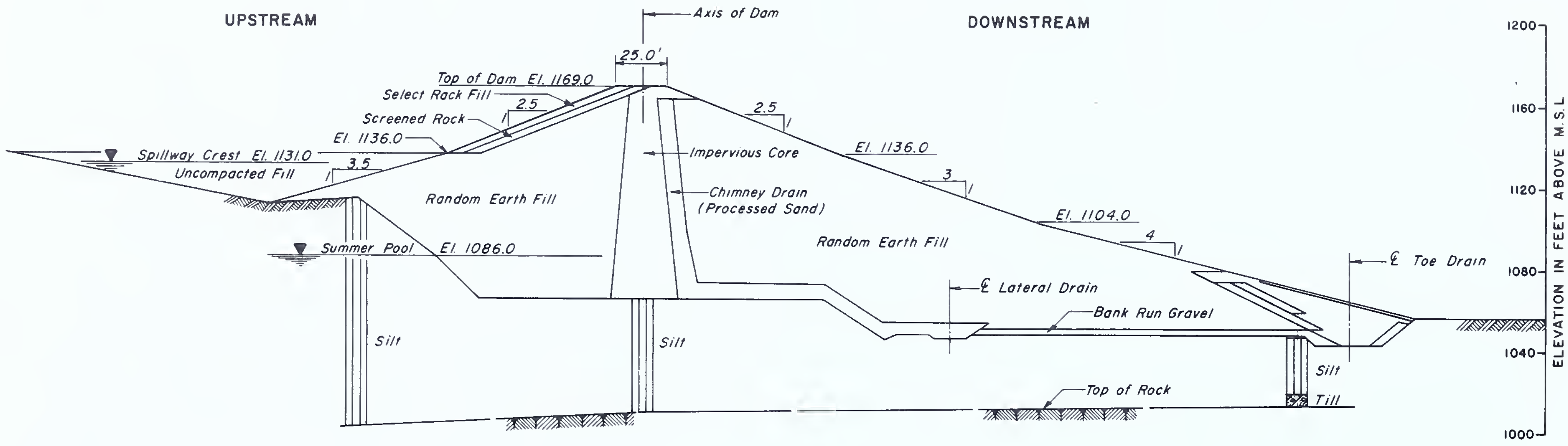


Figure 25. Hammond Dam Embankment Cross Section.

STA. 40+00 H

an internal drainage system; (4) Install a surface drainage system (Plate 4, A and B) placing rock protection in selected areas; and (5) Install instrumentation to monitor slide conditions.

Repair of the slide was completed in 1978 at a cost of approximately $3.5 million with no renewed movement in the area to date.

This was one of Pennsylvania's biggest landslides.

A. Part of the surface drainage configuration at the repaired toe of the Tioga landslide. The right (east) abutment of the Tioga Dam is in the background.

B. Surface drainage along the flank of the repaired Tioga landslide. Note slope indicator in left background.

PLATE 4

REFERENCES CITED

Abel, K. D., and Heyman, L., 1981, The Oriskany Sandstone in the subsurface of Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 81, 9 p.

Aber, J. S., 1980, Nature and origin of exotic-rich drift in the Appalachian Plateau: American Journal of Science, v. 280, p. 363-384.

Allen, J. R. L., 1965, Fining-upwards cycles in alluvial successions: Liverpool and Manchester Geological Journal, v. 4, p. 229-246.

_____ and Friend, P. F., 1968, Deposition of the Catskill facies, Appalachian region: with notes on some other Old Red Sandstone basins, in Klein, G. deV., ed., Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geological Society of America Special Paper 106, p. 21-74.

Anon., 1883, History of Tioga County, Pennsylvania: W. W. Munsell & Co., N. Y., 367 p. Reproduction by Unigraphic, Ind., Evansville, Inc., 1977. Biography 35 p., Index of names 55 p.

Anon., 1897, History of Tioga County, Pennsylvania: R. C. Brown & Co., 186 p.

Ashburner, C. A., 1880, The geology of Mckean County and its connection with that of Cameron, Elk, and Forest: Pennsylvania Geological Survey 2nd series, Report R., 282 p.

Ashley, G. H., 1945, The Grand Canyon of Pennsylvania: Pennsylvania Department of Internal Affairs Monthly Bulletin, v. 13, no. 7, p. 3-7, 28.

_____ and Cathcart, S. H., 1932, Gas in the Tioga region, Pennsylvania: Pennsylvania Geological Survey, 4th series, Progress Report 102A, 11 p.

_____, Cathcart S. H., Willard B., and Fettke, C. R., 1931, Gas in the Tioga region, Pennsylvania (Edition of August 10, 1931): Pennsylvania Geological Survey, 4th series, Progress Report 102 (Revised), p. 1, 2; A1-E2.

Ayrton, W. G., 1963, Isopach and lithofacies map of the Upper Devonian of northeastern United States, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th series, General Geology Report 39, p. 3-6.

Bambach, R. K., Scotese, C. R., and Ziegler, A. M., 1980, Before Pangea: the geographies of the Paleozoic world: American Scientist, v. 68, p. 26-38.

Banks, H. P., 1966, Devonian flora of New York State: Empire State Geogram, v. 4, p. 10-24.

Barrell, J., 1913, The Upper Devonian delta of the Appalachian geosyncline: Part I. The delta and its relations to the interior sea: American Journal of Science, 4th series, v. 36, p. 429-472.

____, 1914, The Upper Devonian delta of the Appalachian geosyncline: Part III. The relations of the delta to Appalachia: American Journal of Science, 4th series, v. 37, p. 225-253.

Berg, T. M., 1973, Pelecypod burrows in the basal sandstone member of the Catskill Formation, northeastern Pennsylvania [abs.]: Geological Society of America, Abstracts with Programs, v. 5, no. 2, p. 137.

_____, 1975, Geology and mineral resources of the Brodheadsville quadrangle, Monroe and Carbon Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Atlas 205a, 60 p., 2 maps.

_____, 1977, Bivalve burrow structures in the Bellvale Sandstone, New Jersey and New York: New Jersey Academy of Science Bulletin, v. 22, p. 1-5.

_____, 1979, Upper Devonian-Lower Mississippian stratigraphic relations in north-central Pennsylvania [abs.]: Geological Society of America Abstracts with Programs, v. 11, p. 3.

_____ and Edmunds, W. E., 1979, The Huntley Mountain Formation: Catskill-to-Burgoon transition in north-central Pennsylvania: Pennsylvania Geological Survey, 4th series, Information Circular 83, 80 p.

_____, Edmunds, W. E., Geyer, A. R., and others, 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th series, Map 1, scale 1:250,000.

_____, and Glover, A. D., 1976, Geology and mineral resources of the Sabula and Penfield quadrangles, Clearfield, Elk, and Jefferson Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Atlas 74 ab, 98 p.

_____, Sevon, W. D., and Bucek, M. F., 1977, Geology and mineral resources of the Pocono Pines and Mount Pocono quadrangles, Monroe County, Pennsylvania: Pennsylvania Geological Survey, 4th series, Atlas 204cd, 66 p. 2 maps.

Bird, J. M. and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen: Geological Society of America Bulletin, v. 81, p. 1031-1060.

Bottjer, R. J., 1981, Depositional environments of an Upper Devonian Sandy Coquinite: Unpublished Honors Thesis, SUNY Binghamton, Binghamton, NY 75 p.

Bowen, Z. P., Rhoads, D. C., and McAlester, A. L., 1974, Marine benthic communities in the Upper Devonian of New York: Lethaia, v. 2, p. 93-120.

Bradley, W. H. and Pepper, J. F., 1938, Structure and gas possibilities of the Oriskany sandstone in Steuben, Yates, and parts of the adjacent counties, New York: U. S. Geological Survey Bulletin 899-A, 68 p.

Bradsby, H. C., 1891, History of Bradford County, Pennsylvania with biographical selections: S. B. Nelson & Co., Publishers , Chicago, 320 p.

Burtner, R. L., 1964, Paleocurrent and petrographic analysis of the Catskill facies of southeastern New York and northeastern Pennsylvania: Ph.D thesis, Harvard University, Cambridge, Massachusetts, 222 p.

Buttner, P. J. R., 1968, Proximal continental rhythmic sequences in the Genesee Group (lower Upper Devonian) of southeastern New York, in Klein, G. deV., ed., Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geological Society of America Special Paper 106, p. 109-126.

_____, 1977, Physical stratigraphy, sedimentology and environmental geology of the Upper Devonian stream deposits of the Catskill Mountains of eastern New York State, in Wilson, P. C., Guidebook to field excursions: New York State Geological Association, 49th Annual Meeting, Oneonta, Trip A-7, p. 1-25.

Butts, Charles, and Moore, E. S., 1936, Geology and mineral resources of the Bellefonte quadrangle, Pennsylvania: U. S. Geological Survey Bulletin 855, 108 p.

Caster, 1934, The stratigraphy and paleontology of northwestern Pennsylvania, Part I: Stratigraphy: Bulletin of American Paleontology, v. 21, no. 71, 185 p.

_____, 1938, A restudy of the tracks of Paramphibus: Journal of Paleontology, v. 12, p. 3-60.

Cate, A. S., 1962, Subsurface structure of the plateau region of north-central and western Pennsylvania on top of the Oriskany Formation: Pennsylvania Geological Survey, 4th series, Map 9.
Cathcart, S. H., 1934, Geologic structure of the plateau region of northern Pennsylvania and its relation to the occurrence of gas in the Oriskany sand: Pennsylvania Geological Survey, 4th series, Progress Report 108, 24 p.
_____ and Myers, T. H., 1934, Gas in Tioga County, Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin 107 (Progress Report), 42 p.
_____ and Willard, B., 1931, Gas in the Tioga Region, Pennsylvania (Edition of April 17, 1931): Pennsylvania Geological Survey, 4th series, Progress Report 102, p. A1-D4.
Chadwick, G. H., 1933a, Upper Devonian of the New York region [abs.]: Geological Society of America Bulletin, v. 44, p. 177.
_____, 1933b, Great Catskill delta, and revision of Late Devonic succession: Pan-American Geologist, v. 60, p. 91-107, p. 189-204, p. 275-286, p. 348-360.
_____, 1935, What is "Pocono"?: American Journal of Science, 4th series, v. 29, p. 133-143.
Chaloner, W. G. and Sheerin, A., 1979, Devonian macrofloras, in House, M. R., Scrutton, C. T., and Bassett, M. G., eds., The Devonian System: Palaeontological Association, London, Special Papers in Palaeontology, No. 23, p. 145-161.
Chance, H. M., 1880, The Geology of Clinton County (Pennsylvania); Report of Progress, Parts I and II: Pennsylvania Geological Survey, 2nd series, Rept. G4, 72 p.
Coates, D. R., 1966a, Glaciated Appalachian Plateau: till shadows on hills: Science, v. 152, p. 1617-1619.
_____, 1966b, Report on Geomorphology of the Cowanesque Basin: U. S. Army Corps of Engineers Cowanesque Reservoir Study, Baltimore, Maryland, 27 p.
_____, 1974, Reappraisal of the glaciated Appalachian Plateau, in Glacial geomorphology, D. R. Coates, ed., Publication in Geomorphology: State University of New York, Binghamton, New York, p. 205-243.
_____ and Kirkland, J. T., 1974, Application of glacial models for large-scale terrain developments, p. 99-136, in W. C. Mahaney, ed., Quaternary Environments: Proceedings of a symposium, York, Ontario, 318 p.
Collins, H. R., 1979, Devonian Bentonites in Eastern Ohio: American Association of Petroleum Geologists Bulletin, v. 63, p. 655-660.
Collinson, J. D., 1978, Lakes, in Reading, H. G., ed., Sedimentary environments and facies: Blackwell Scientific Publications, Oxford, 557 p.
Colton, G. W., 1963a, Bedrock geology and surface structure of the Cedar Run quadrangle, Tioga and Lycoming Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Progress Report 164.
_____, 1963b, Devonian and Mississippian correlations in part of north central Pennsylvania--a report of progress, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th series, General Geology Report 39, p. 115-125.
_____, 1967, Surface structure map of parts of Lycoming, Clinton, Tioga, and Potter Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Map 14.
_____, 1970, The Appalachian Basin-its depositional sequences and their

geologic relationships, in Fisher, G. W. and others, eds., Studies of Appalachian geology: central and southern: New York, Interscience Publishers, p. 5-47.
_____ and Luft, S. J., 1965, Bedrock geology of the Slate Run quadrangle, Clinton, Lycoming, and Potter Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Progress Report 167.
Cook, T. D. and Bally, A. W., eds., 1975, Stratigraphic atlas of North and Central America: Princeton, New Jersey, Princeton University Press, 272 p.
Corps of Engineers, Tioga-Hammond Lakes. Significant Data Book: Baltimore District, Baltimore, Maryland.
Craft, D., 1878, History of Bradford County, Pennsylvania: L. H. Everts & Co., Philadelphia, 492 p. + IX.
Crowl, G. H. and Sevon, W. D., 1980, Glacial border deposits of Late Wisconsinan age in northeastern Pennsylvania: Pennsylvania Geological Survey, 4th series, General Geology Report 71, 68 p.
Dennison, J. M., 1970, Stratigraphic divisions of Upper Devonian Greenland Gap Group ("Chemung Formation") along Allegheny Front in West Virginia, Maryland, and Highland County, Virginia: Southeastern Geology, v. 12, p. 53-82.
_____ and deWitt, W., Jr., 1972, Redbed zone produced by sea level drop at beginning of Devonian Cohocton age delimits Fulton and Augusta Lobes of Catskill delta complex, in Dennison, J. M. and others, Stratigraphy, sedimentology, and structure of Silurian and Devonian rocks along the Allegheny Front in Bedford County, Pennsylvania, Allegheny County, Maryland, and Mineral and Grant Counties, West Virginia: Guidebook, 37th Annual Field Conference of Pennsylvania Geologists, Pennsylvania Geological Survey, p. 109-114.
_____ and Head, J. W., 1975, Sea level variations interpreted from the Appalachian basin Silurian and Devonian: American Journal of Science, v. 275, p. 1089-1120.
Denny, C. S., 1956, Surficial geology and geomorphology of Potter County, Pennsylvania: U. S. Geological Survey Professional Paper 288, 72 p.
_____ and Lyford, W. H., 1963, Surficial geology and soils of the Elmira-Williamsport region, New York and Pennsylvania: U. S. Geological Survey Professional Paper 379, 60 p.
Dewey, J. F. and Kidd, W. S. F., 1974, Continental collisons in the Appalachian-Caledonian orogenic belt: variations related to complete and incomplete suturing: Geology, v. 2, p. 543-546.
Dietz, R. S., 1972, Geosynclines, mountains, and continent building: Scientific American, v. 226, no. 3, p. 30-38.
Dott, R. H., Jr. and Batten, R. L., 1971, Evolution of the earth: New York, McGraw-Hill Book Co., 649 p.
Duffield, S. L. and Warshauer, S. M., 1981, Upper Devonian (Frasnian) conodonts and ostracodes from the subsurface of West Virginia: Journal of Paleontology, v. 55, p. 72-83.
Epstein, J. B., Sevon, W. D., and Glaeser, J. D., 1974, Geology and mineral resources of the Lehighton and Palmerton quadrangles, Carbon and Northampton Counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Atlas 195cd, 460 p., 4 pls.
Edmunds, W. E., Berg, T. M., Sevon, W. D., Piotrowski, R. C., Heyman, Louis, and Rickard, L. V., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States--Pennsylvania and New York:

U. S. Geological Survey Professional Paper 1110-B, 33 p.
Ettensohn, F. R. and Barron, L. S., 1981, Depositional model for the Devonian-Mississippian black-shale sequence of North America: a tectonoclimatic approach: U. S. Department of Energy, DOE/METC/12040-2, Distribution Category UC-92a, 80 p.
Fairchild, H. L., 1895, Glacial Genessee Lakes: Geological Society of America Bulletin, v. 7, p. 423-452.
Fergusson, W. B. and Prather, B. A., 1968, Salt deposits in the Salina Group in Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 58, 41 p.
Fettke, C. R., 1950, Summarized Record of Deep Wells in Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin M31.
_____, 1956, Summarized Records of Deep Wells in Pennsylvania 1950-1954: Pennsylvania Geological Survey, 4th series, Bulletin M39.
_____ and Willard, B., 1931, Physical characteristics of the Oriskany Sandstone and subsurface studies in the Tioga gas field, Pennsylvania: Pennsylvania Geological Survey, 4th series, Progress Report 102B, 14 p.
Ferm, J. C., 1970, Allegheny deltaic deposits, in Morgan, J. P., ed., Deltaic sedimentation modern and ancient: Society of Economic Paleontologists and Mineralogists, Special Publication 15, p. 245-255.
Fletcher, F. W., 1964, Middle and Upper Devonian stratigraphy of southeastern New York: Ph.D thesis, University of Rochester, 78 p.
_____ and Woodrow, D. L., 1970, Geology and economic resources of the Pennsylvania portion of the Milford and Port Jervis 15-minute quadrangles: Pennsylvania Geological Survey, 4th series, Atlas 223, 64 p.
Friedman, G. M., 1972, "Sedimentary facies": products of sedimentary environments in Catskill Mountains, Mohawk Valley, and Taconic sequence, eastern New York State: Guidebook, Society of Economic Paleontologists and Mineralogists, Eastern Section, 48 p.
_____ and Johnson, K. G., 1966, The Devonian Catskill deltaic complex of New York, type example of a "tectonic delta complex," in Shirley, M. L. and Ragsdale, J. A., eds., Deltas in their geologic framework: Houston Geological Society, p. 171-188.
Fuller, J. O., 1955, Source of the Sharon conglomerate in northeastern Ohio: Geological Society of America Bulletin, vol. 66, pp. 159-176.
Fuller, M. L. and Alden, W. C., 1903a, Description of the Gaines quadrangle: U. S. Geological Survey, Geologic Atlas of the U. S., Folio 92, 9 p.
_____, 1903b, Description of the Elkland and Tioga quadrangles: U. S. Geological Survey, Atlas of the U. S., Folio 93, 9 p.
Geological Sample Log Company, 1960, Log No. P-29: The California Company, No. 1, A. W. Bennett, Sulivan Co., Pennsylvania.
Geological Sample Log Company, 1967, Log No. P-1396: Consolidated Gas Co., No. 1, Pennsylvania Department of Forests and Waters tract 129, Potter County, Pennsylvania.
Glaeser, J. D., 1969, Geology of flagstones in the Endless Mountains region, northern Pennsylvania: Pennsylvania Geological Survey, 4th series, Information Circular 66, 14 p.
_____, 1973, Pocono boundary discrepancy between eastern and western Pennsvlvania (abs.): Geological Society of America, Abstracts with Programs, v. 5, no. 2, p. 166.
_____, 1974, Upper Devonian stratigraphy and sedimentary environments in northeastern Pennsylvania: Pennsylvania Geological Survey, 4th series, General Geology Report 63, 89 p.

_____, 1979, Catskill delta slope sediments in the central Appalachian basin: Source deposits and reservoir deposits, in Doyle, L. J. and Pilkey, O. H., eds., Geology of continental slopes: Society of Economic Paleontologists and Mineralogists, Special Publication 27, p. 343-357.

Glenn, L. C., 1903, Devonic and Carbonic formations of southwestern New York: New York State Museum Bulletin 69, p. 967-989.

Gwinn, V. E., 1964, Thin-Skinned Tectonics in the Plateau and Northwestern Valley and Ridge Provinces of the Central Appalachians: Geological Society of America Bulletin, v. 75, no. 9, pp. 863-900.

Harris, L. D., 1975, Oil and gas data from the Lower Ordovician and Cambrian rocks of the Appalachian basin: U. S. Geological Survey, Miscellaneous Investigation Series I-917D.

Hatcher, R. D., Jr., 1972, Developmental model for the southern Appalachians: Geological Society of America Bulletin, v. 83, p. 2735-2760.

Heckel, P. H. and Witzke, B. J., 1979, Devonian world palaeogeography determined from distribution of carbonates and related lithic palaeoclimatic indicators, in House, M. R., Scrutton, C. T., and Bassett, M. G., eds., The Devonian System: Palaeontological Association, London, Special Papers in Palaeontology No. 23, p. 99-123.

Heverly, C. F., 1924, History and Geography of Bradford County, Pennsylvania 1615-1924, 594 p. Reproduction by Unigraphic, Inc., Evansville, Ind., 1976 with subject index by C. W. Northrup, 1936 and name index by E. R. Gleck 1976.

Heyman, L., 1977, Tully (Middle Devonian) to Queenston (Upper Ordovician) correlations in the subsurface of western Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 73, 16 p.

House, M. R., Scrutton, C. T., and Bassett, M. G., eds., 1979, The Devonian System: Palaeontological Association, London, Special Papers in Palaeontology No. 23, 353 p.

Humphreys, M. and Friedman, G. M., 1975, Late Devonian Catskill deltaic complex in north-central Pennsylvania, in Broussard, M. L., ed., Delta models for exploration: Houston Geological Society, p. 369-379.

_____, 1981, Uranium Concentrations in Upper Devonian Clastic Rocks of North-central Pennsylvania: Northeastern Geology, v. 3, no. 2, p. 138-143.

Ingham, A. I., 1961, Geologic structures of the Northern Plateaus region of Pennsylvania: Pennsylvania Geological Survey, 4th series, Progress Report 138 (map).

Johnson, G. J. and Friedman, G. M., 1969, The Tully clastic correlatives (Upper Devonian) of New York State: a model for recognition of alluvial, dune(?), tidal, nearshore (bar and lagoon), and offshore sedimentary environments in a tectonic delta complex: Journal of Sedimentary Petrology, v. 39, p. 451-485.

Jones, T. H., and Cate, A. S., 1957, Preliminary report on a regional stratigraphic study of Devonian rocks of Pennsylvania: Pennsylvania Geological Survey, 4th series, Special Bulletin 8, 5 p., 7 plates.

Kaiser, W. R., 1972, Delta cycles in the Middle Devonian of central Pennsylvania: Ph.D thesis, The Johns Hopkins University, Baltimore, Maryland, 183 p.

Kelley, D. R., Lytle, W. S., Wagner, W. R., and Heyman, L., 1970, The petroleum industry and future petroleum provinces in Pennsylvania, 1970: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 65, 39 p.

Kent, B. H. and Gomez, M., 1971, Paleotopographic structural controls on thickness and composition of Pittsburgh coal in southwestern Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 3,

no. 7, p. 622.
Kirby, M. W., 1981, Sedimentology of the Middle Devonian Bellvale and Skunnemunk Formations in the Green Pond Outlier in northern New Jersey and southeastern New York: M.S. thesis, Rutgers, The State University of New Jersey, New Brunswick, 109 p.
Klemic, H., 1962, Uranium occurrences in sedimentary rocks of Pennsylvania: U. S. Geological Survey Bulletin 1107-D, p. 243-288.
Krajewski, S. A. and Williams, E. G., 1971, Upper Devonian flagstone from northeastern Pennsylvania: The Pennsylvania State University, College of Earth and Mineral Science Experiment Station, Special Publication 3-71, 185 p.
Kramers, J. W. and Friedman, G. M., 1971, The Centerfield Limestone and its clastic correlatives (Middle Devonian, New York): A sedimentologic analysis (abs.): Geological Society of America Abstracts with Programs, v. 3, no. 1, p. 40.
Leighton, M. M. and Ray, L. L., 1965, Glacial deposits of Kansan and Nebraskan age in Northern Kentucky: U. S. Geological Survey Professional Paper 525B, p. B126-B131.
Le Pichon, X., 1968, Sea-floor spreading and continental drift: Journal of Geophysical Research, v. 73, p. 3661-3697.
Lesley, J. P., 1859, The Iron Manufacturer's Guide: John Wiley, New York, 772 p.
Lucier, W. A., 1966, The petrology of the Middle and Upper Devonian Kiskatom and Kaaterskill Sandstones: A vertical profile: Ph.D thesis, University of Rochester, 92 p.
Lytle, W. S., 1963, Underground Gas Storage in Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report, M46.
_____, 1975, Oil and gas developments in Pennsylvania in 1974: Pennsylvania Geological Survey, 4th series, Progress Report 188, 38 p.
_____ and others, 1961, A Summary of Oil and Gas Developments in Pennsylvania 1955 to 1959: Pennsylvania Geological Survey, 4th series, Bulletin M45.
MacClintock, P. and Apfel, E. T., 1944, Correlation of the drifts of the Salamanca re-entrant, New York: Geological Society of America Bulletin, v. 55, p. 1143-1164.
Manspeizer, W., 1969, The Catskill delta complex: distributaries in the Bradford subdelta (abs.): Geological Society of America Abstracts with Programs, v. 4, no. 1, p. 39.
Matthews, R. K., 1974, Dynamic Stratigraphy: Prentice-Hall, Inc., Englewood, Cliffs, New Jersey, 370 p.
McCauley, J. F., 1961, Uranium in Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 43, 71 p.
McCave, I. N., 1968, Shallow and marginal marine sediments associated with the Catskill complex in the Middle Devonian of New York, in Klein, G. deV., ed., Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geological Society of America Special Paper 106, p. 75-107.
_____, 1969, Correlation of marine and nonmarine strata with example from Devonian of New York State: American Association of Petroleum Geologists Bulletin, v. 53, p. 155-162.
_____, 1973, The Sedimentology of a transgression: Portland Point and Cooksburg Members (Middle Devonian), New York State: Journal of Sedimentary Petrology, v. 43, p. 484-504.

McCreath, A. S., 1879, Second Report of Progress in the Laboratory of the Survey at Harrisburg: Pennsylvania Geological Survey, 2nd series, v. MM, 438 p.
McCulloch, C. M., Diamond, W. P., Bench, B. M., and Deul, M., 1975, Selected geologic factors affecting mining of the Pittsburgh coal bed: U. S. Bureau of Mines Report of Investigation 8093, 72 p.
McGannon, D. E., Jr., 1975, Primary fluvial oolites: Journal of Sedimentary Petrology, v. 45, p. 719-727.
McGhee, G. R., Jr., Sutton, R. G., 1981, Late Devonian marine ecology and zoogeography of the central Appalachians and New York: Lethaia, v. 14, p. 27-43.
Meckel, L. D., Jr., 1964, Pottsville sedimentology--central Appalachians: Ph.D thesis, Johns Hopkins University.
_____, 1967, Origin of the Pottsville conglomerates (Pennsylvanian) in the central Appalachians: Geological Society of America Bulletin, v. 78, no. 2, pp. 223-257.
Mencher, E., 1939, Catskill facies of New York State: Geological Society of America Bulletin, v. 50, p. 1761-1794.
Miller, M. F., 1979, Paleoenvironmental distribution of trace fossils in the Catskill deltaic complex, New York State: Palaeogeography, Palaeoeclimatology, Palaeoecology, v. 28, p. 117-141.
Moore, R. C. and others, 1944, Correlations of Pennsylvanian Formations of North America: Geological Society of America Bulletin, v. 55, p. 657-706.
Murphy, P. J., 1981, Detachment Structures in South-Central New York: Northeastern Geology, v. 3, no., 2, p. 105-116.
Oliver, W. A. and Klapper, G., 1981, Devonian Biostratigraphy of New York, Part I-Text: International Union of Geological Sciences, Subcommission on Devonian Stratigraphy: W. A. Oliver, Smithsonian Institution, Washington, D. C., 106 p.
Park, C. F., Jr. and MacDiarmid, R. A., 1964, Ore Deposits, San Francisco: W. H. Freeman and Co., 475 p.
Pelletier, B. R., 1958, Pocono paleocurrents in Pennsylvania and Maryland: Geological Society of America Bulletin, v. 69, p. 1033-1064.
Perry, W. J., Jr. and deWitt, W., Jr., 1977, A field guide to thin-skinned tectonics in the central Appalachians: Guidebook, post-meeting field trip no. 4, American Association of Petroleum Geologists/Society of Economic Paleontologists and Mineralogists Annual Meeting, Washington, D. C., 54 p.
Piotrowski, R. G. and Harper, J. A., 1979, Black shale and sandstone facies of the Devonian "Catskill" clastic wedge in the subsurface of western Pennsylvania: U. S. Department of Energy, Eastern Gas Shales Project Series No. 13, 40 p., 39 plates.
Piotrowski, R. G. and Krajewski, S. A., 1977, Preliminary stratigraphic cross section (D_3-D_4) showing radioactive black shale zones and sandstones in the Middle and Upper Devonian, western Pennsylvania: U. S. Department of Energy, Eastern Gas Shales Project Series No. 6, 2 sheets.
Pohn, H. A., 1981, Joint spacing as a method of locating faults: Geology, vol. 9, no. 6, p. 258-262.
_____ and Purdy, T. L., 1979, Thrust fault zones in the Allegheny Plateau of north-central Pennsylvania: U. S. Geological Survey Open-file Report 70-1604, 4 p., 8 figs.
Price, P. H., 1931, The Appalachian structural front: Journal of Geology, v. 39, p. 24-44.

Rahmanian, V. D., 1979, Stratigraphy and sedimentology of the Upper Devonian Catskill and uppermost Trimmers Rock Formations in central Pennsylvania: Ph.D thesis, The Pennsylvania State Univeristy, University Park, 340 p.

_____ and Williams, E. G., 1979, Tide-dominated deltaic-interdeltaic sedimentation, Upper Devonian, Pennsylvania (abs.): Abstracts with Program, 14th Annual Meeting, Northeast Section, Geological Society of America, p. 50.

Rankin, D. W., 1975, The continental margin of eastern North America in the southern Appalachians: the opening and closing of the proto-Atlantic ocean: American Journal of Science, v. 275-A, p. 298-336.

Ray, L. L., 1974, Geomorphology and Quaternary geology of the glaciated Ohio River Valley - a reconnaissance study: U. S. Geological Survey, Professional Paper 876, 77 p.

Read, C. B. and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: U. S. Geological Survey Professional Paper 454-K, 35 p.

Reed, L. A., 1980, Effects of strip mining the abandoned deep Anna S mine on the hydrology of Babb Creek, Tioga County, Pennsylvania: U. S. Geological Survey Water Resources Investigations 80-53, 41 p.

Reineck, H. E. and Wunderlick, F., 1968, Classification and origin of flaser and lenticular bedding: Sedimentology, v. 11, p. 99-104.

Rickard, L. V., 1969, Stratigraphy of the Upper Silurian Salina Group New York, Pennsylvania, Ohio, Ontario: New York State Museum and Science Service, Map and Chart Series No. 12, 57 p.

_____, 1975, Correlation of the Devonian and Silurian rocks in New York State: New York State Museum and Science Service, Map and Chart Series, no. 24.

Roen, J. B., 1980, Stratigraphy of the Chattanooga and Ohio Shales and equivalents in the Appalachian Basin: An example of long-Range subsurface correlation using Gamma-ray logs: United States Department of Energy, Morgantown Energy Technology Center, Morgantown, West Virginia, 26 p.

_____, Wallace, L. G. and DeWitt, W., 1978, Preliminary stratigraphic cross-section showing radioactive zones in the devonian black shales in eastern Ohio and west-central Pennsylvania: United States Geological Survey, Oil and Gas Investigations Chart OC-82.

Rogers, H. D., 1858, The geology of Pennsylvania, a government survey: Vol. I and II, J. B. Lippincott & Co., Philadelphia, v. I, 586 p., v. II, 1045 p.

Rose, A. W., 1970, Metal mines and occurrences in Pennsylvania: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 50, Part 3, 14 p.

Schenk, P. E., 1971, Southeastern Atlantic Canada, northwestern Africa, and continental drift: Canadian Journal of Earth Science, v. 8, p. 1218-1251.

Seaman, S. J., 1979, The lowermost unit of the Spechty Kopf Formation: composition and possible source areas: Senior research paper, Bryn Mawr College, 16 p.

Selley, R. C., 1976, An Introduction to sedimentology: Academic Press, New York, 408 p.

Sevon, W. D., 1969, The Pocono Formation in northeastern Pennsylvania: Guidebook, 34th Annual Field Conference of Pennsylvania Geologists, Pennsylvania Geological Survey, 129 p.

_____, 1979a, Devonian sediment-dispersal systems in Pennsylvania (abs.): Geological Society of America Abstracts with Programs, v. 11, no. 1, p. 53.

_____, 1979b, Polymictic diamictites in the Spechty Kopf and Rockwell Formations, in, Dennison, J. M. and others, Devonian shales in south-central Pennsylvania and Maryland: Guidebook, 44th Annual Field Conference of Pennsylvania Geologists, Pennsylvania Geological Survey, p. 61-66; 107-110.

_____, Rose, A. W., Smith, R. C., II, and Hoff, D. T., 1978, Uranium in Carbon, Lycoming, Sullivan, and Columbia Counties, Pennsylvania: Guidebook, 43rd Annual Field Conference of Pennsylvania Geologists, Pennsylvania Geological Survey, 99 p.

Shaffner, M. N., 1958, Geology and mineral resources of the New Florence quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th series, Atlas 57, 165 p.

Sherwood, A., Platt, F., and Fulton, J., 1878, Report of progress in Bradford and Tioga Counties: Pennsylvania Geological Survey, 2nd series, Report G, 271 p.

Sisler, J. D., 1926, Bituminous coal fields of Pennsylvania, Part II, detailed description of coal fields: Pennsylvania Geological Survey, 4th series, Mineral Resource Report 6, Part II, 511 p.

Stout, W., VerSteeg, K., and Lamb, G. F., 1943, Geology of water in Ohio: Ohio Geological Survey, 4th series, Bulletin 44, 694 p.

Sulenski, R. J., 1969, The paleoenvironments and fossil communities of the Bellvale Sandstone (Middle Devonian) and Skunnemunk Conglomerate (Middle Devonian?) at Skunnemunk Mountain, New York: M.A. thesis, Queens College, New York, 138 p.

Sutton, R. G., 1963, Correlation of Upper Devonian strata in south-central New York in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th series, General Geology Report 39, p. 87-101.

_____, Bowen, Z. P., and McAlester, A. L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geological Society of America Bulletin, v. 81, p. 2975-2992.

Swadley, W. C., 1979, New evidence supporting Nebraskan age for origin of Ohio River in northcentral Kentucky: U. S. Geological Survey Professional Paper 1126H, p. H1-H7.

Thayer, C. W., 1974, Marine paleoecology in the Upper Devonian of New York: Lethaia, v. 2, p. 121-155.

Van Houten, F. B., 1976, Late Variscan nonmarine deposits, northwestern Africa: implications for pre-drift North Atlantic reconstructions: American Journal of Science, v. 276, p. 671-693.

_____ and Bhattacharyva, C., 1981, Phanerozoic oolitic ironstones - A facies model (abs.): Abstracts and Proceedings, Institute on Lake Superior Geology, 27th Annual Meeting.

_____ and Karasek, R. M., 1981, Sedimentological Framework of Late Devonian Oolitic Iron Formation, Shatti Valley, West-Central Libya: Journal of Sedimentary Petrology, v. 51, p. 415-427.

Wagner, W. R., 1966, Stratigraphy of the Cambrian to Middle Ordovician rocks of central and western Pennsylvania: Pennsylvania Geological Survey, 4th series, General Geology Report 49, 156 p.

_____, 1976, Growth faults in Cambrian and Lower Ordovician rocks of western Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 60, p. 414-427.

Walker, G. H. and Jewett, C. F., 1875, County Atlas of Tioga Pennsylvania: F. W. Beers & Co., New York, 109 p.

Walker, R. G., 1971, Non-Deltaic Depositional Environments in the Catskill Clastic Wedge (Upper Devonian) of Central Pennsylvania: Geological Society of America Bulletin, v. 82, p. 1305-1326.

_____, 1972, Upper Devonian marine-nonmarine transition southern Pennsylvania: Pennsylvania Geological Survey, 4th series, General Geology Report 62, 25 p.

_____ and Harms, J. C., 1971, The "Catskill Delta" - A prograding muddy shoreline in central Pennsylvania: Journal of Geology, v. 79, p. 381-399.

Walther, J., 1894, Lithogenesis der Gegenwart, Beobachtungen uber die Bildung der Gesteine an der heutigen Erdoberflache, dritten Teil einer Einleitung in die geologische historische Wissenschaft: Verlag Gustav Fischer, Jena, section 8, p. 621.

Ward, J. R., 1981, Preimpoundment water quality in the Tioga River basin, Pennsylvania and New York: U. S. Geological Survey Water Resources Investigations 81-1, 142 p.

West, Mareta, 1978, Preliminary Stratigraphic Cross-Sections showing Radioactive Zones in the Devonian Black Shales in the Eastern Part of the Appalachian Basin: United States Geological Survey, Oil and Gas Investigations Chart OC-86.

White, C. D., 1900, The stratigraphic succession of the fossil floras of the Pottsville Formation in the Southern Anthracite Coal Field, U. S. Geological Survey, Annual Report 20, Part 2, pp. 749-930.

_____, 1904, Deposition of the Appalachian Pottsville: Geological Society of America Bulletin, v. 15, p. 267-282.

Willard, B., 1932a, Devonian Faunas in Pennsylvania: Pennsvlvania Geological Survey, 4th series, Bulletin G-4, 43 p.

_____, 1932b, Glacial Lake Cowanesque: Geological Society of America Bulletin, v. 43, p. 441-448.

_____, 1934, Early Chemung shore line in Pennsylvania: Geological Society of America Bulletin, v. 45, p. 897-908.

_____, 1936, Continental Upper Devonian of Northeast Pennsylvania: Geological Society of America Bulletin, v. 47, p. 565-607.

_____, Swartz, F. M. and Cleaves, A. B., 1939, The Devonian of Pennsylvania: Pennsylvania Geological Survey, 4th series, Bulletin G-19, 481 p.

Williams, E. G. and Bragonier, W. A., 1974, Controls of Early Pennsylvanian sedimentation in western Pennsylvania, in Briggs, G., ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 135-152.

Williams, H. S., and Kindle, E. M., 1905, Contributions to Devonian Paleontology 1903: U. S. Geological Survey Bulletin 244, 144 p.

Woodrow, D. L., 1963, Post-Rhinestreet stratigraphy in the Sayre and Towanda quadrangles, Pennsylvania: A progress report, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th series, General Geology Report 39, p. 79-85.

_____, 1968a, Upper Devonian aestivation tube-casts (abs.): Geological Society of America, Special Paper 121, p. 383-384.

_____, 1968b, Stratigraphy, Structure and Sedimentary Patterns in the Upper Devonian of Bradford County, Pennsylvania: Pennsylvania Geological Survey, General Geology Report G54, 78 p.

_____ and Enos P., Bottjer, R. J. and Minero, C., 1981, Unusual Bioclastic Carbonate Units in the Catskill Clastic Wedge: Fieldtrip Guidebook, 53rd Annual Meeting, New York State Geological Association, Binghamton,

New York.
_____ and Fletcher, F. W., 1967, Late Devonian palaeogeography in southwestern New York and northeastern Pennsylvania, in Oswald, D. H, ed., International symposium on the Devonian System: Calgary, Alberta Society of Petroleum Geologists, v. 2, p. 1327-1334.
_____ and Fletcher, F. W., and Ahrnsbrak, W. F., 1973, Paleogeography and climate at the deposition sites of the Devonian Catskill and Old Red Facies: Geological Society of America Bulletin, v. 84, p. 3051 - 3064.
_____ and Isley, A. M. (in revision), Facies, bottom topography and sedimentary processes in the Catskill sea (Devonian), New York and Pennsylvania: Geological Society of America Bulletin.
_____ and Nugent, R. C., 1963, Facies and the Rhinestreet Formation: Fieldtrip Guidebook, 35th Annual Meeting, New York State Geological Association, Binghamton, New York, p. 59-76.
Woodward, H. P., 1963, Upper Devonian stratigraphy and structure in northeastern Pennsylvania, in Shepps, V. C., ed., Symposium on Middle and Upper Devonian stratigraphy of Pennsylvania and adjacent states: Pennsylvania Geological Survey, 4th series, General Geology Report 39, p. 279-301.
Wright, N. A., 1973, Subsurface Tully Limestone New York and northern Pennsylvania: New York State Museum and Science Service, Map and Chart Series No. 14, 15 p.
Ziegler, A. M., Scotese, C. R., McKerrow, W. S., Johnson, M. E., and Bambach, R. K., 1979, Paleozoic paleogeography: Annual Reviews of Earth and Planetary Science, v. 7, p. 473-502.

ADDENDUM:

Blatt, H., Middleton, G., and Murray, R., 1980, Origin of sedimentary rocks, second edition, Prentice-Hall, Inc., New Jersey, 782 p.
Kantz, B., and Associates, 1976, Operation Scarlift, Babb Creek mine drainage abatement project: Pennsylvania Department of Environmental Resources, Scarlift Report, 125 p.

ROAD LOG AND STOP DESCRIPTIONS
(Route map on inside of back cover)

DAY 1

Friday, 2 October, 1981

Inc. Mil.	Cum. Mil.	Description
0.0	0.0	LEAVE rear parking lot of Penn-Wells Hotel.
0.1	0.1	STOP SIGN; TURN RIGHT onto Queen St.
0.1	0.2	STOP LIGHT; CONTINUE STRAIGHT ahead onto U. S. Route 6, eastbound (Grand Army Rep. Hwy.).
0.2	0.4	STOP LIGHT; CONTINUE STRAIGHT ahead.
0.5	0.9	Corning Glass Plant on left; All shiny brite (Tm) Christmas ornaments were made here. Penn Wells lobby flag came from here.
1.5	2.4	Outcrop on right; Lock Haven Formation sandstone and some shale.
0.7	3.1	Outcrop on right; evenly interbedded siltstone and shale of Lock Haven Formation. Willard (1932) lists five outcrops and their faunules as his Locality 20. Outcrops occur at 2.7; 2.9; 3.8, thin bed of hematite; 5.4; and 5.7 with hematite; miles from Wellsboro. This outcrop would be his faunule 53b site.
0.2	3.3	Outcrop on right; shale with some thin siltstone beds, Lock Haven Formation.
0.4	3.7	Outcrop on right; shales of Lock Haven Formation.
0.4	4.1	Crossroads; About 0.8 miles to the North the "Arieno Shaft" was sunk on the creek bank. Ten to twenty thousand dollars was spent looking for anthracite coal in "Chemung" rocks (Sherwood, 1878). Road to left leads to Hills Creek State Park.
0.9	5.0	Outcrop on right; dark brown shale and some siltstone beds (near top of outcrop), Lock Haven Formation.
1.4	6.4	Junction of U. S. Route 6 and PA Route 660. CONTINUE STRAIGHT ahead on U. S. Route 6.
2.4	8.8	Roadcut through fossiliferous interbedded siltstone and shale, and some thin sandstone beds of the Lock Haven Formation.

0.8	9.6	Outcrop on left of dark brown shale overlain by very thin oolitic iron ore, followed by thin-bedded siltstone and sandstone, all Lock Haven Formation. Loadcasts at east end of outcrop. Very fossiliferous.
0.7	10.3	Outcrop on right of dark brownish gray shale and interbedded thin siltstones of the Lock Haven Formation. Fossiliferous. Some pencil siltstone.
0.4	10.7	Orebed Road to left (Route to Stop 9, Day 2).
1.9	12.6	Old Mansfield Iron Furnace was located just to the south.
0.1	12.7	Tioga River; Rip-rap is Pottsville sandstone quarried at Brownlee.
0.2	12.9	STOP LIGHT; Intersection of U. S. Routes 15 and 6 in Mansfield. CONTINUE STRAIGHT ahead on U. S. Route 6.
0.1	13.0	Mansfield State College on Right.
1.7	14.7	Junction with PA Route 549.
3.2	17.9	Mainesburg; BEAR LEFT on U. S. Route 6. Much of the local water supply is sulphurous.
6.0	23.9	Enter Bradford County.
0.1	24.0	Roadside rest on left.
0.3	24.3	Outcrop on right.
0.1	24.4	Armenia Mountain Summit; elevation 1775 feet.
0.1	24.5	Discontinuous outcrops of Catskill Formation on right.
0.9	25.4	Exposures of Catskill Formation on left for next 0.1 miles.
0.9	26.3	Intersection; road to left goes north to Austinville. Iron mine is 2.35 miles north.
1.1	27.4	Outcrop on right of Catskill Formation.
2.6	30.0	Troy Borough limits.
0.2	30.2	STOP LIGHT.
0.2	30.4	STOP LIGHT; junction with PA Route 14. CONTINUE AHEAD on U. S. Route 6 and PA Route 14.
0.5	30.9	Exposure behind gasoline station on left of stratified sands and gravel in valley side kame overlying Catskill Formation.

0.1	31.0	Outcrop of Catskill Formation behind gasoline station on left.
0.1	31.1	Road junction; CONTINUE AHEAD on U. S. Route 6. PA Route 14 goes left to Elmira.
0.4	31.5	Begin series of outcrops of Catskill Formation on both sides of road. Note large exposure on left across concrete retaining wall.
2.3	33.8	Road to Mt. Pisgah State Park on left.
2.1	35.9	Late Wisconsinan outwash plain on right.
0.6	36.5	West Burlington.
1.2	37.7	Mid-valley kame on right.
0.6	38.3	Outcrops of Lock Haven Formation on left.
0.3	38.6	Outcrops of Lock Haven Formation on left.
0.8	39.4	Bradford County Manor on right; In 1822, while digging a cellar for Gen. Samuel McKean, two stone sarcophagi were found. They were both 9 feet by 2½ feet by 2 feet. Skeletons 8'2" were found with sound teeth, but very soft bones. A three foot diameter pine was growing over one of them (Craft, 1878).
0.3	39.7	Enter Burlington.
1.1	40.8	STOP 1. Luthers Mills Coquinite, Louis Case Quarry, Burlington, PA. Discussant: D. L. Woodrow. Buses will pull into quarry and turn around there.

Strike: N85E; Dip: 5NW.

Data on which this summary is based are from Bottjer (1981) and Woodrow (1968, unpublished). Bottjer's work is to date the most comprehensive study of the rocks in this quarry.

Stratigraphy

The Pennsylvania Geological Survey assigns these rocks to the Lock Haven Formation (Berg and others, 1981). Woodrow (1968) assigned the Luthers Mills Coquinite and the rocks overlying it to the Towanda Formation. These rocks are thought to be equivalent to the lower part of the Canadaway Group of New York. They belong, therefore, in the Cassadaga stage or the Famennian stage of European usage (Rickard, 1975).

The name Luthers Mills comes from the village east of the quarry. When the unit was first recognized by Sherwood (Sherwood and others, 1878) he referred to it as the Burlington Limestone, a name preoccupied and later rejected by Willard (1936) in favor of Luthers Mills. The shelly rocks in this unit, exposed at the older quarry 40 m to the east, are the type for

Willard's term coquinite (1932) and is his Locality 24, faunule 57.

Stratigraphic equivalents are known to the east as far as the hilltops east of Towanda. However, from the scattered nature of the exposures and the extreme variation in texture and color of the rocks involved, it appears likely that the Luthers Mills is a discontinuous rock unit.

Lithology and Sedimentary Structures

Rocks in the quarry are readily divided into the coquinite, of which 15-plus meters are exposed in the quarry, and the rocks above. Additional outcrops of the coquinite east of the quarry and 8 m below indicate that it is at least 23 m thick. The overlying rocks are a heterogeneous mix of shale, sandstone and coquinites.

The coquinite contains more than 30 percent matrix and cement (Table 1), much of which has been recrystallized. For purposes of classification the two components have been treated as matrix and the rock can be referred to as a shelly wacke.

Table 8. Petrography of the Luthers Mills Coquinite at the Louis Case Quarry (adapted from Woodrow and others, 1981).

	Shell-rich rocks	Shell-poor rocks
Quartz and chert	14.7	21.5
Rock fragments	21.3	37.5
Fossils	32.9	9.7
Matrix and Cement		
Carbonate	17.4	18.5
Hematite	13.6	12.9

Many of the coquinite beds are cross-stratified with troughs opening to the west or northwest or with plane beds inclined in that direction. Lunate and sinuous ripples on sandstone interbeds rarely show current reversals, that is, flow to the east or southeast.

Shells in individual beds are usually found in the hydrodynamically stable, convex-up position, but some beds show a chaotic fabric due either to rapid deposition or to the effects of bioturbation. On a few cross-sets, shells accumulated at the toe with large wood fragments farther updip. Where exposure is sufficient to see cross-strata surfaces, ripples are found with crests parallel to the down-dip direction of sets or they are perpendicular to it with the inferred direction of transport up the dip of the sets.

Shells show the effects of transport in that they are sorted and arranged as indicated above. Most show detailed preservation of fine-structure and whole or articulated shells have been found.

Shales in the coquinite are red or green and appear to have accumulated as mud drapes over bedforms made up of shelly sand. Thin interbeds of shale define the 10-20 cm thick stratification of the coquinite. Clasts of shale are a major part of many coquinite beds. Unit 10, (Figure 26) the shale

just above the coquinite, is in sharp contact with it. This shale is the same texture as the shales within the coquinite and it contains scattered shells of Cyrtospirifer. Were it not for the lack of coquinite, the Luthers Mills would be extended to include this unit.

The rocks above the coquinite include sandstones, mudstones, shales and coquinites. The sandstones are fine-grained, thin-bedded, laminated and less than 30 cm thick. A notable exception is in unit 19 where one sandstone is fine-to medium-grained, cross-stratified and lenticular. The cross-strata are inclined toward 353° and the unit thins dramatically in that same direction. Asymmetric ripples developed in these cross-sets indicate flow toward the south. A thin sandstone in unit 19 has on it a lag deposit of quartz granules, shell fragments, bone fragments and phosphate(?) nodules.

Shales and mudstones in the upper beds are silty, often bioturbated and most are red (5R). Units 12 and 14 have in them small carbonate nodules which appear to be pedogenic and unit 14 has in it both large and small burrows. Units 10, 18 and 20 contain brachiopods, fish plates and plant impressions.

Fossils

The Luthers Mills is a brachiopod coquinite with bivalves and bryozoa as lesser elements (Table 2). The brachiopods and bivalves occur as disarticulated and size-sorted shells. Some of the bryozoa obviously lived on the coquinite surface because there they formed small, mound-shaped colonies (Plate 5-A) or they grew as individual zooecia enclosing shell or bone material. (Plate 5-B)

Trace fossils are also a prominent feature of the coquinite (Figure 26). Perhaps the most distinctive are the Asterosoma-like burrows found on the base of coquinite beds and the unnamed horizontal burrows (Asterosoma?) with spreiten found within the coquinite beds. Less distinctive and smaller vertical burrows and tracks are also present.

Plant fragments, one of them 1 m long and 8 cm wide, have been pyritized where they occur as coaly lenses. Bone fragments of fish, many centimeters on the longest dimension, are scattered throughout the unit. Tiny, blue-weathering fish plates occur in many coquinite beds. Small disarticulated fish plates and teeth are found in the units above the coquinite.

Interpretation

That most of the rocks in the quarry formed in marine environments is demonstrated by the presence of brachiopods, crinoids and bryozoa. Exceptions are units 12, 14 and 18 which contain what appear to be pedogenic carbonate nodules, root impressions and the impressions of whole plant fronds. Rocks in those units must have formed under subaerial circumstances.

The coquinite appears to be the product of deposition on an ebb-dominated tidal delta. Tidal influence is suggested by (1) the intimate interbedding of sandstone and shale and the presence of shale as clay drapes, (2) the evidence of current reversals, and (3) the presence of material from both

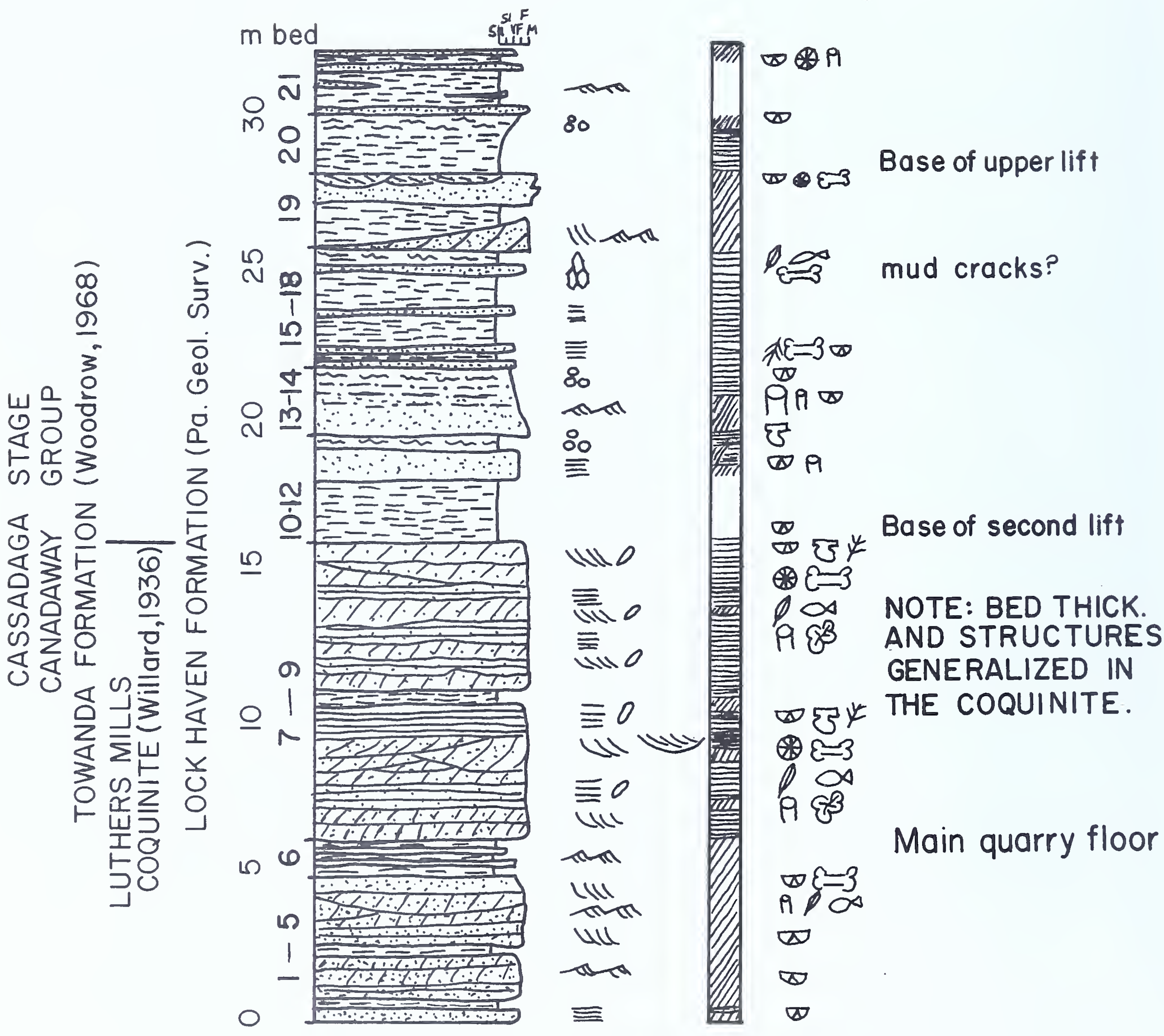
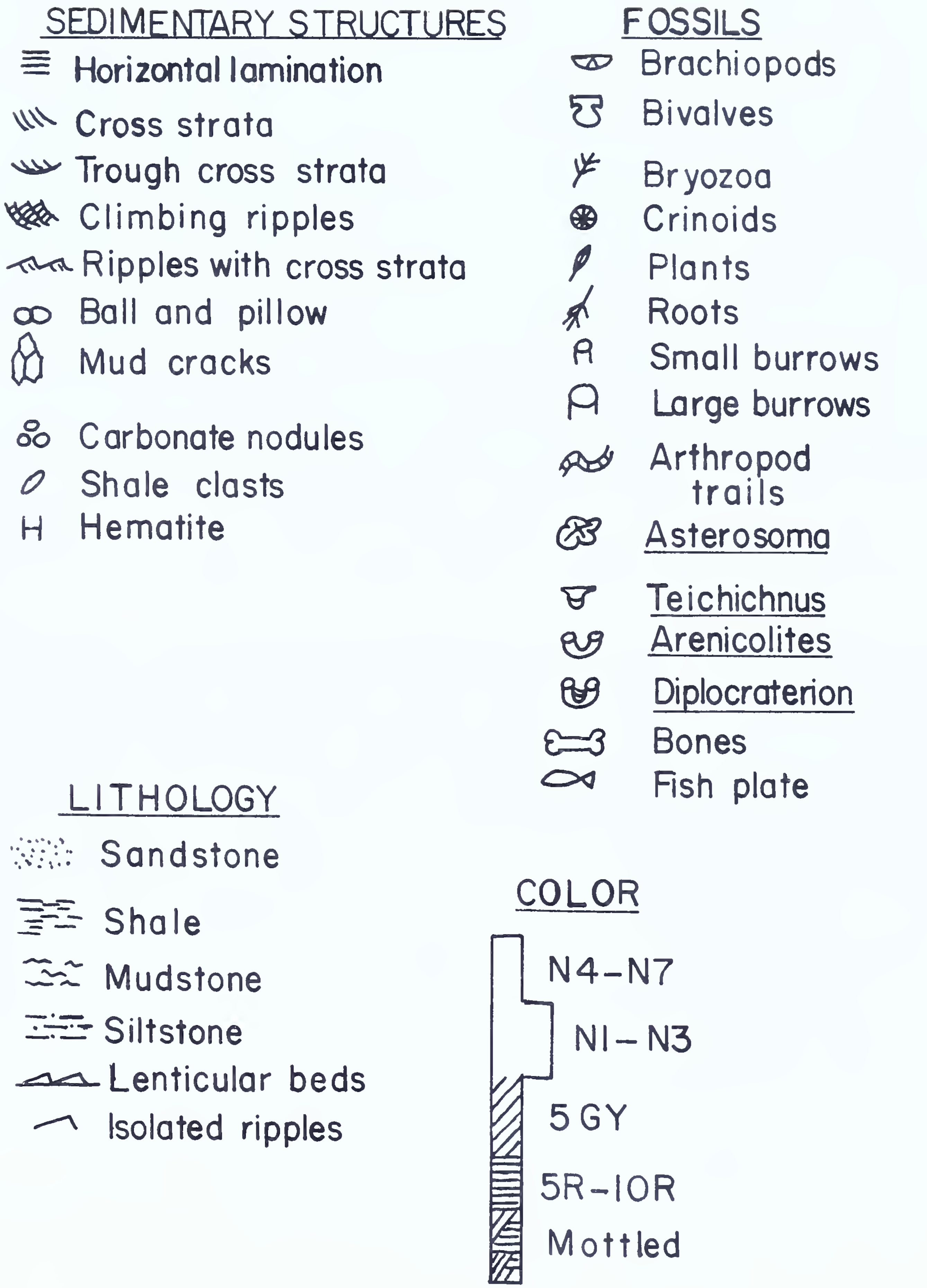
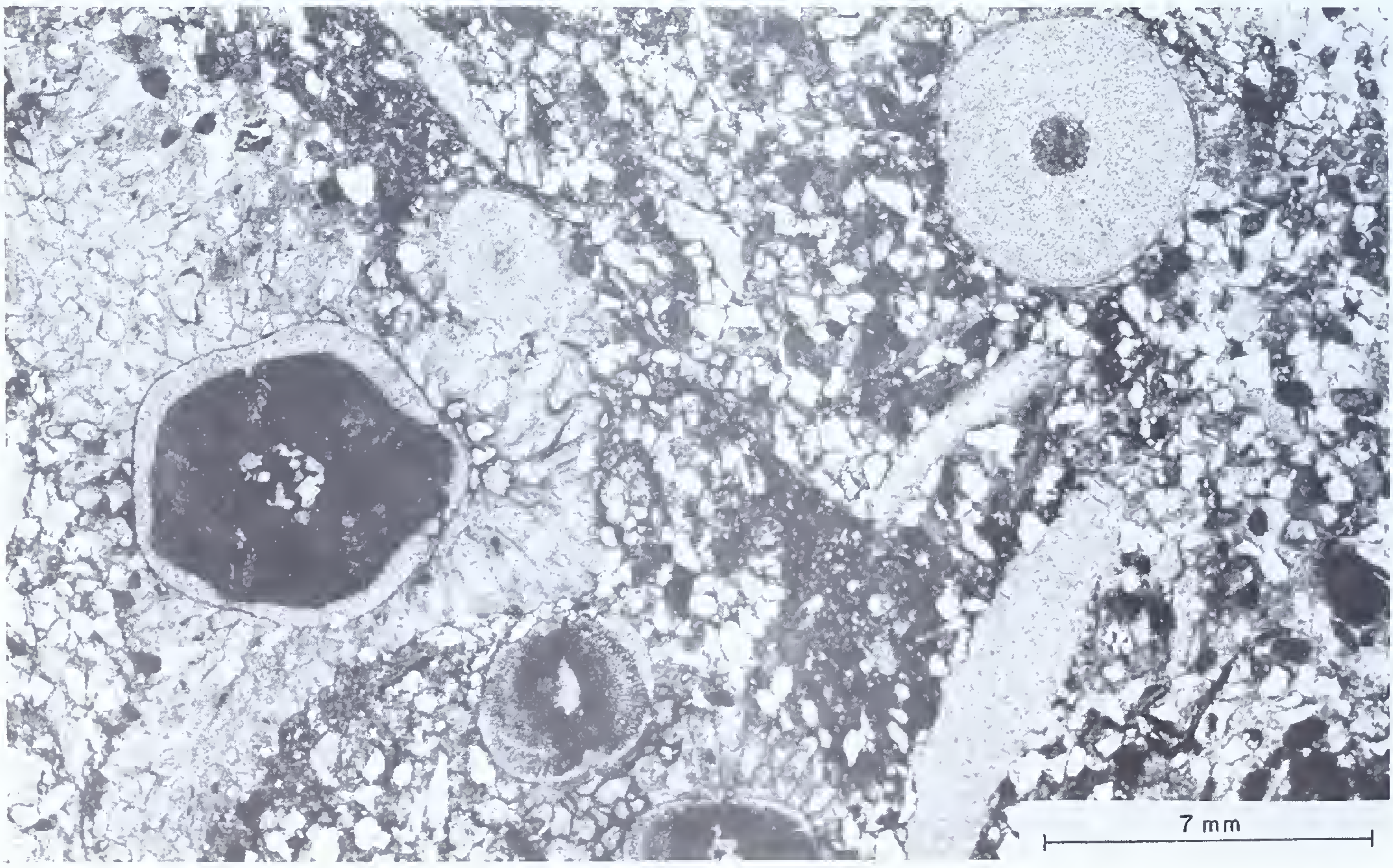


Figure 26. Stratigraphic column for rocks of the Lock Haven Formation exposed in the Louis Case Quarry, Burlington, Pennsylvania. Top of the Luthers Mills Coquinite is base of second lift. Symbols used in this column are keyed on opposite page.



Symbols used in stratigraphic columns for Stops 1, 2, 3, and 10 (Figures 26, p. 108; 27, p. 114; 28, p. 119; and 34, p. 148 respectively).

A. Photomicrograph of Luthers Mills Coquinite. Bryozoa in center floats as a clast in a hematite-rich, mud matrix and that, in turn, is inside a brachiopod fragment. Other clasts include bryozoa, brachiopod, and unidentified fossils fragments, quartz and rock fragments.



B. Photomicrograph of Luthers Mills Coquinite. Bryozoa on left encrusts a bone(?) fragment in which dolomite rhombs are floating.

PLATE 5

Table 9. Fossils from the Luthers Mills Coquinite and overlying strata (Bottjer, 1981; Woodrow, 1968 and unpublished).

Luthers Mills Coquinite

Brachiopods
- *Cyrtospirifer* sp.
- *Athyris* sp.
- *Camarotoechia* sp.

Bivalves
- *Nuculoidea corbuliformis*
- *Grammysia circularis*
- *Eschizodus chemungensis*
- *Cryptonella* sp.

Bryozoa
- *Lioclema* cf. *subramosa*
- *Ridotrypella parbulipora*
- *Batostomella* sp.

Crinoids

Fish plates Arthrodires?

Fish bones Antiarchs?

Plant fragments

Plant impressions *Archeopteris halli*

Trace fossils
- *Asterosoma* *Teichichnus* *Skolithos*

Fossils from the overlying strata

Brachiopods	Bivalves	Trace Fossils
Cyrtospirifer sp.	*Nuculoidea* sp.	*Beaconites*
Athyris sp.	*Glossites* sp.	*Cruziana*
Camarotoechia sp.	*Grammysia* sp.	*Planolites*
Leiorhynchus sp.		*Skolithos*
Productella sp.		*Teichichnus*
Hamburgia vera		

Crinoids; fish plates and bones; plant impressions; plant fragments.

marine sources (shells) and terrestrial sources (plant fragments, red muds). Ripple asymmetry, cross-bed orientations, and trough orientations indicate flow toward the west or northwest and, therefore, ebb-flow (Woodrow and others, 1981).

A likely depositional situation is as follows. Shells, derived from a population of invertebrate epifauna dominated by *Athyris* and *Cyrtospirifer*, were swept from the nearby seafloor on the flood tide. During ebb, muds swept from a nearby tidal flat or distributary lobe were mixed with the shells and moved seaward (Woodrow and others, 1981). If a distributary lobe is the source of the red mud, the dominance of ebb over flood reflects the additive effect of tidal water "damming" fresh water in the stream for a short time and then loosing it as a flow much greater than that of the flood. Much sediment would be flushed out onto the shell-rich floor and a shell mud mass would be deposited. The presence of the bryozoa indicates that we are not dealing with single tidal cycles in each coquinite stratum. Sufficient time must have been available between the deposition of a coquinite mass and the growth on it of the bryozoa to permit clear water conditions to become

the norm. These beds may record, therefore, either storm-enhanced tidal effects or deposition by annual major tides.

The rocks above the coquinite record the infilling of this marine locale by the progradation of distributary lobes. A return to marine conditions is demonstrated at the top, perhaps with tidal effects.

LEAVE STOP 1 and return to U. S. Route 6. TURN RIGHT and CONTINUE east on U. S. Route 6.

0.3	41.1	Outcrops of Lock Haven Formation on left. Outwash plain and alluvium on right.
0.8	41.9	Crossing flood plain.
0.4	42.3	Luthers Mills township line.
1.4	43.7	Picnic table on left.
0.2	43.9	Outcrops of Lock Haven Formation on right.
0.8	44.7	Outcrops of Lock Haven Formation on both sides.
0.3	45.0	Kame on right (looking back slightly).
0.7	45.7	Roadcut in kame.
0.8	46.5	Outcrops of Lock Haven Formation on both sides.
0.6	47.1	Glacial till on the right with some slumping.
0.3	47.4	State Police barracks to the right.
0.1	47.5	U. S. Route 220 southbound bears off to right; CONTINUE AHEAD on U. S. Route 6 east.
0.2	47.7	U. S. Route 220 northbound to the left; CONTINUE AHEAD on U. S. Route 6 east.
1.0	48.7	Crossing Sugar Creek. Outwash/alluvial plain on right.
0.3	49.0	Entering North Towanda.
1.2	50.2	Bradford County PennDOT maintenance garage on left.
0.9	51.1	Bradford County Court House on left. Get into right lane. Stephen Foster, the great writer of folk songs and ballads lived in Towanda in 1840-41. He attended Towanda Academy on the hill a short time and stayed with his brother William, a canal official.
0.1	51.2	STOP LIGHT at Bridge Street; TURN RIGHT, follow Bridge Street up hill.

0.5 51.7 Pass under U. S. Route 220.

0.1 51.8 STOP 2. Bridge Street fault and Lock Haven Formation. Discussants: H. A. Pohn and D. L. Woodrow. Buses should proceed to the top of the hill and make a "U" turn at a wide area just before road narrows and houses occur. Buses return and park on berm opposite outcrop.

Strike: N80E; dip: 4NW

Stratigraphy

The Pennsylvania Geological Survey refers to these beds as the Lock Haven Formation (Berg and others, 1981). Woodrow (1968) assigned them to the Nunda Formation of the West Falls Group in the Cohocton Stage. That assignment makes them part of the Frasnian Stage of European usage (Rickard, 1975). At the time of Woodrow's mapping, these exposures did not exist and the presence of the Towanda Fault at this location was not detected. Total displacement along the fault is not certain (Pohn, pers. comm.), but it does not appear to be sufficient to force revision of the stratigraphic assignment of the units involved. As can be seen from the stratigraphic columns (Figure 27), it is not possible to match the sequences across the fault.

Lithology and Sedimentary Structures

The rocks in both parts of the sequence are fine-grained. Sandstones are gray, fine- to very fine-grained and many have horizontal laminations. Basal contacts of sandstones are usually sharp, often with small scour marks, and the top contacts are often gradational. Many sandstones are lenticular or they have been deeply scoured and the resulting channels filled with mud (unit 17, upper). Scouring relationships often are complicated and multiple sand units are common (Unit 7, lower; unit 17, upper). Ripples are seen on many sandstone surfaces and as isolated structures in shales (unit 11, upper). Cross-strata are developed as large ripples, small dunes or as surfaces built into channels (units 15, 17, upper; unit 7, lower). Thin discontinuous coquinites occur as the base of many sandstones in the upper sequence (units 2, 13, 18). Ball-and-pillow structures are found at many horizons both in the lower and in the upper sequences. Coarsening-upward sequences provide a degree of organization in both sequences. These shale-to-sandstone couplets are suggested in the stratigraphic columns, for example, in the lower sequence: units 1-3, 14-15 and in the upper sequence: units 12-13 and 17-18, however, they are difficult to define in the exposure due to the lack of deep weathering.

The finer grained rocks are silty gray and dark-gray shales, gray mudstones and siltstones. These are complicated units in that they have in them isolated sand ripples (units 11, 13; upper) or sand lenses (units 1, 6, 8, 16; lower and units 11, 13, 16; upper), small mud-filled channels (units 14, upper) and ball-and-pillow structures (units 1, 4; upper).

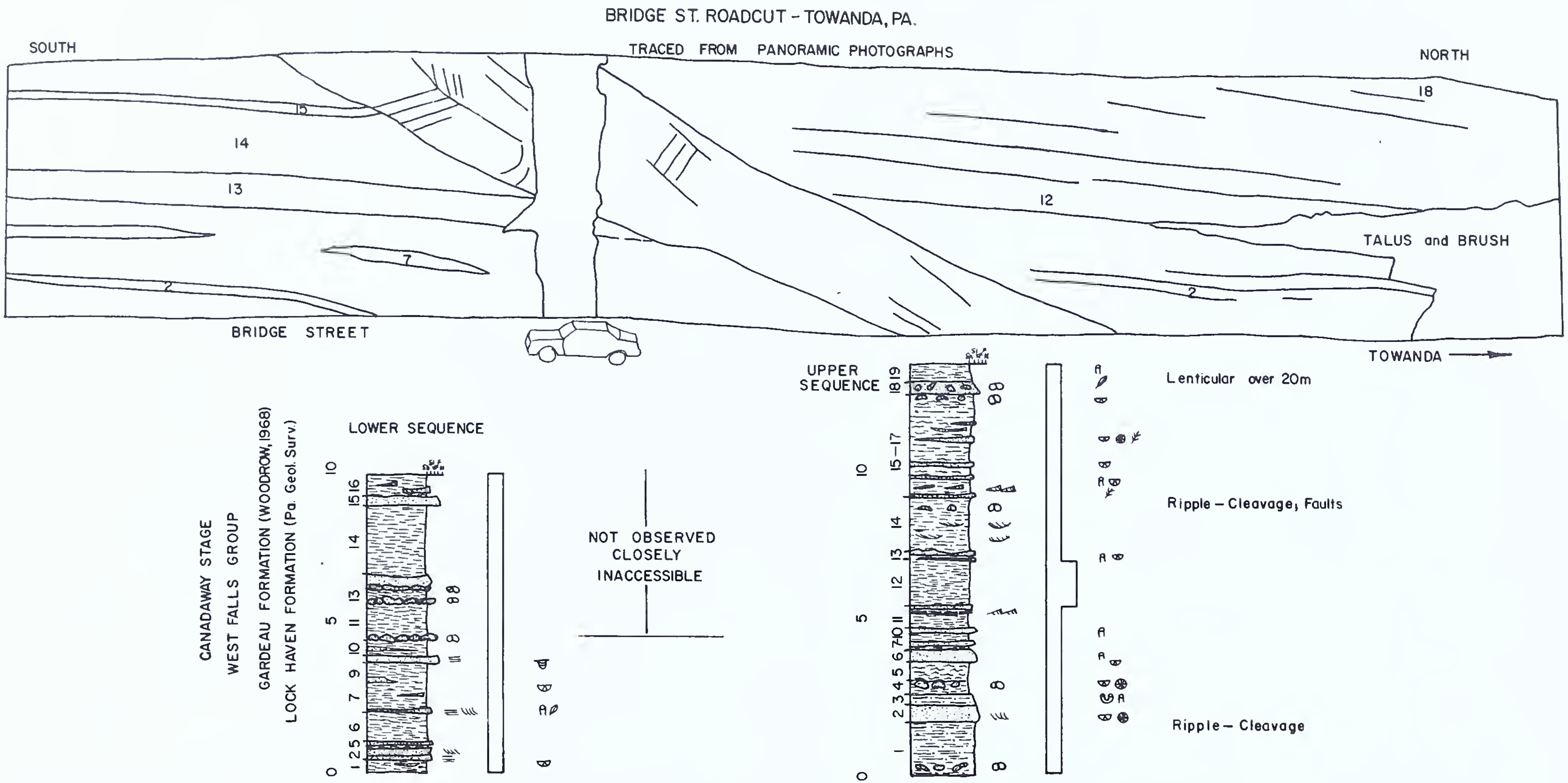


Figure 27. Diagrammatic sketch of the Bridge Street roadcut, Towanda, Pennsylvania, with accompanying stratigraphic columns of the Lock Haven Formation (see Figure 26 for key).

Fossils

Fossils are more common in the upper sequence than they are in the lower one. Small *Camarotoechia* sp. have been collected from units 1 and 8 in the lower sequence. Fragments of brachiopods, crinoids, bivalves(?) and bryozoa make up thin coquinites at the base of sandstones in the upper sequence. Very few body fossils are found in the shales or mudstones either above or below the fault.

Trace fossils include small, vertical burrows like *Skolithos*, sand-filled tubes in shales (*Planolites*?), U-shaped burrows (*Arenicolites*) and vertical burrows with spreiten (*Teichichnus*). Only the *Skolithos*-like burrows are common.

Fine plant debris is found in many beds, especially on the top of unit 7 (lower) where it is pyritized. No bones, plates of fish or large plant fragments have been found here.

Interpretation

All of these rocks are marine as evidenced by the presence of brachiopods, crinoids, and bryozoa. Their fine grain size, relative lack of fauna and the low number of thick sandstones indicate that they formed where deposition from suspension was dominant and where sediment reworking by strong bottom currents was limited. Development of ball-and-pillow structures and the lack of heavily bioturbated surfaces further suggests rapid deposition. These rocks appear then to have been deposited on a marine surface distant from shore where wave-generated bottom currents had little effect. Much of sediment was deposited from suspension or by plane-bed flow. The most likely location is on the distal part of a sand/mud mass being built seaward from a prograding delta platform. Alternatively, some of the sandstones may have been deposited as the distal part of delta-front sands and the lenticular beds may be a result of transport on to the prodelta or open shelf during storms. Channeling of the sands and muds with later infilling by muddy sediment may be the result of rare storm-reworking of the sediment mass.

Structure

This roadcut may be the best exposure of thrust faults in the Allegheny plateau of north-central Pennsylvania. The fault zone itself is composed of 3 antithetic faults, the lowermost fault giving rise to a small splay fault. The minimum stratigraphic displacement is 14 m but may be as much as 25 m. Greater displacement than this would juxtapose sandstone on the upper plate against the siltstone and shale seen in the outcrop (D. L. Woodrow, pers. comm.).

The fault zone is approximately 3 m wide at the lower north end, narrows to 2 m in the middle, and widens to 5 m at the top of the outcrop. The upper slices of rock trapped between the bounding faults have been rotated and folded.

Beginning at the north end of the fault zone, are (1) a beheaded open anticline, and (2) a series of overturned anticlines whose axial planes

change from steeply dipping at their bases to nearly flat against the upper fault. The detailed sequence of faulting that produces such overturned folds is not entirely understood, but clearly in the zone between the upper 2 faults, the lower fault moved first. This initial movement rotated the south limbs to an overturned position by normal drag. The upper fault moved next, produced overturned folds, and smeared out the anticlinal noses. Between the 2 episodes there must have been sufficient time to lock the lower fault, although the length of time necessary for this locking is unknown. The zone between the middle fault and the lower fault shows that the sequence of events was the same as in the upper zone; however, in the lower fault zone, the beds were more intensely disrupted than those in the upper zone. At least 3 episodes of fault movements are indicated in the outcrop; time was sufficient between the movements to produce locking of the earlier faults.

North of the fault zone, a group of beds just above the uppermost fault have a peculiar cleavage that produces a sinusoidal overprint accompanied by minute uplimb thrust faults in the essentially flat lying beds (Plate 6). Apparently the combination of cleavage plus bedding produces acicular cleavage, commonly known as pencil cleavage. We believe cleavage to be presumptive evidence of faulting in other localities on the plateau where fault surfaces cannot be identified because of the paucity and poor quality of exposures.

LEAVE STOP 2 and retrace route to stop light.

0.6	52.4	STOP LIGHT at intersection of U. S. Route 6 and old U. S. Route 220. TURN RIGHT on old U. S. Route 220 southbound.
0.2	52.6	Towanda post office on right.
1.6	54.2	Outcrop on right of Lock Haven Formation.
0.2	54.4	STOP SIGN. TURN LEFT onto U. S. Route 220 south. Outcrop of Lock Haven Formation on right. View of Barclay Mountain at 11:00 o'clock.
1.6	56.0	Junction U. S. Route 220 and PA Route 414. TURN RIGHT onto PA Route 414 westbound. View of Barclay Mountain straight ahead.
1.0	57.0	Valley-side kame to the right with active sand and gravel operation. Cobbles and pebbles in this deposit include proportionately large numbers of granite gneiss & granite (garnet-bearing) and questionable metabasalt and anorthosite (identified by R. C. Smith, Pa. Geol. Survey). Most other cobbles are Catskill and Lock Haven lithologies, but some pebbles of probable Potsdam and Medina are also present. The deposit is over 120 ft thick, as reported by operator. [Crusher is on top of hill; operator reports some problems with clay layers].
0.2	57.2	Outcrop of Lock Haven Formation on right, showing relatively steep south dip.

Sinusoidal overprinting and minute uplimb thrusts on flat-lying beds.

PLATE 6

0.1	57.3	Valley-side kame exposed on right opposite iron bridge.
0.1	57.4	Outcrop of Lock Haven Formation shales on right with strike N85W and dip 20S. View of Towanda Creek to left. Picnic table at west end of outcrop.
0.9	58.3	View of imbricated cobbles in mid-channel bar of Towanda Creek to the left.
0.2	58.5	Village of Powell. Travelling on Towanda Creek outwash plain.
1.7	60.2	Entering road cut at east end of Stop 3. Lock Haven-Catskill Formation transition.
0.1	60.3	STOP 3. Roadcut and cliff exposure of the Lock Haven-Catskill Formations transition, Franklindale, Pennsylvania. Discussant: D. L. Woodrow. Buses park on left side of road in pull-off areas in center and west end of roadcut.

Strike: N88E; dip: 14SE

Stratigraphy

The Pennsylvania Geologic Survey refers these rocks to the Lock Haven (gray) and the Catskill Formations (red) (Berg and others, 1981). Correlation with the New York section, based on physical criteria, was proposed by Woodrow (1968) with recognition of shale sequences (Figure units 1 and, perhaps, 38-41) as the easterly equivalents of the Dunkirk Shale (Rickard, 1975). The rocks above the shale are referred to the Towanda Formation of the Canadaway Group. They are part of the Cassadaga Stage or the Famennian Stage of European usage (Rickard, 1975). This is the site of Willard's (1932) Locality 27, faunule 60, and Williams' and Kindle's (1905) "Towanda Narrows section."

Lithology and Sedimentary Structures

Unit 1 is exposed in a gully north of the cliff section and units 26-66 are exposed in the road cut. These units will not be discussed, but their major characteristics are summarized in the stratigraphic column (Figure 28).

The cliff section (Units 2-25, Figure 28; number 2 to the right of the column marks the top of the cliff section and number 1 marks its base) is made up of clearly separable sandstone and shale beds. The sandstones occur as isolated ripples, ripple trains or, as thicker cross-stratified beds. Sandstone bed thickness defines two groups. The more common type is 2-6 cm thick and the other type is characterized by bed thicknesses of 20-40 cm. The thinner beds are rippled, cross-laminated, and display remarkable trace fossils. The thicker sandstones have trough and planar cross-strata, some of it zig-zag. Current directions determined from ripple asymmetry and cross-bed orientation are to the northwest and west and rarely to the east and southeast. Shale chips and shell fragments occur as clasts in both sandstone types. Perhaps the feature which further distinguishes the 2

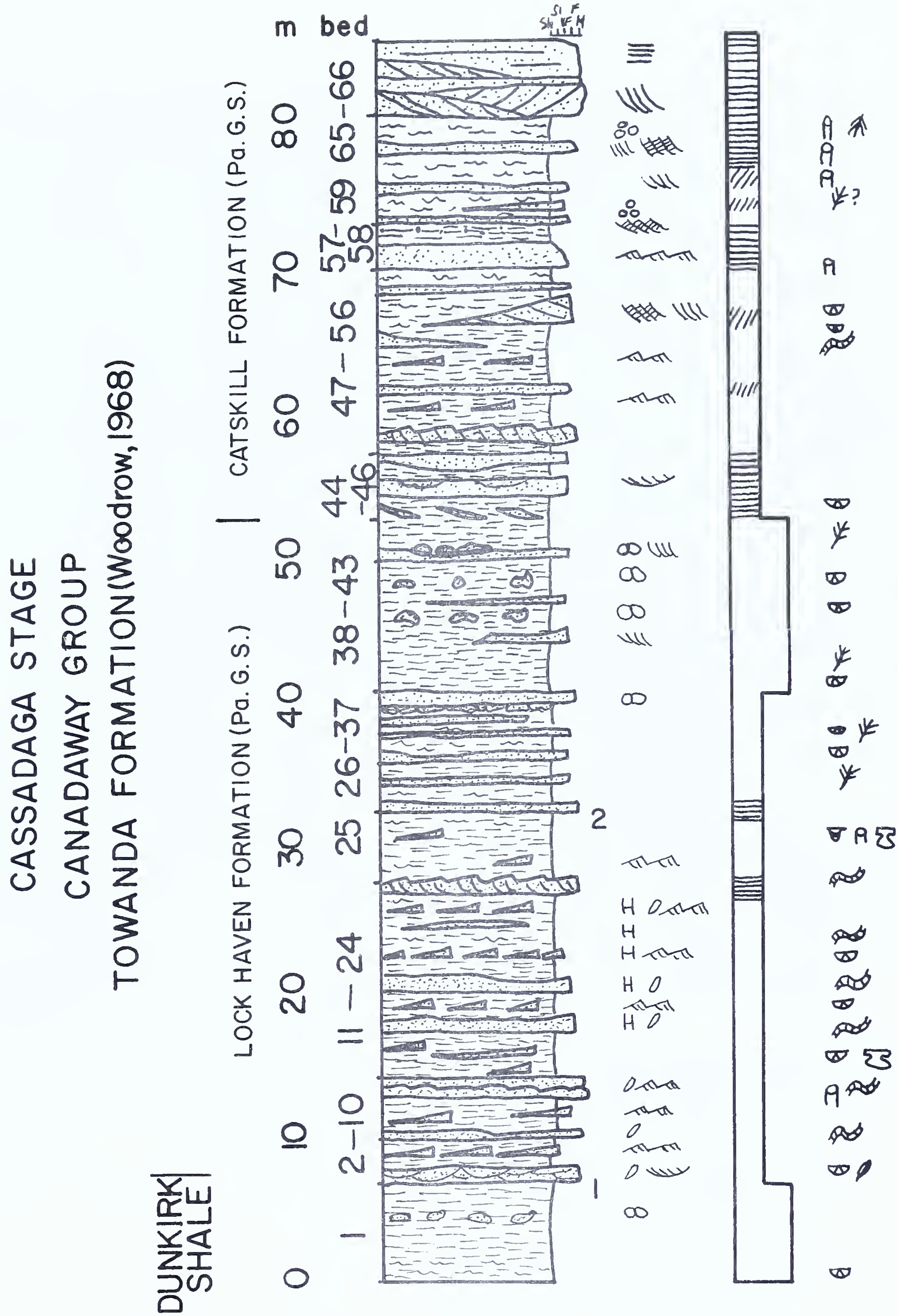


Figure 28. Stratigraphic column of the Lock Haven and Catskill Formations exposed in cliff and roadcut at Franklindale, Pennsylvania (symbols keyed in Figure 26, p. 109).

sandstone types is their weathering color. The thin beds weather to a dull red (5R4/1) and the thicker beds weather to a higher chroma red (10R). The brighter weathering color apparently reflects the presence of relatively large concentrations of hematite in these beds.

Shales in the cliff section are silty, grayish-blue and very thin-bedded to laminated. Many occur as paper-thin strata draped across the surface of ripples.

Fossils

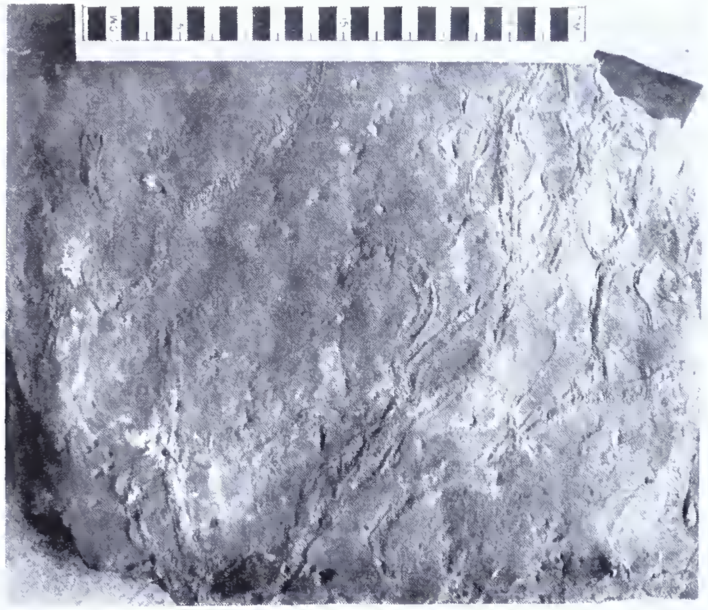
Brachiopods, bivalves, crinoids and bryozoa are found in these rocks. Plant debris occurs as fragments up to 30 cm long and as very fine debris. Concentrations of plant debris are pyritized and weathering of these masses stains parts of the outcrop. Brachiopods include *Cyrtospirifer* sp., *Athyris* sp.(?), *Camarotoechia* sp. and the bivalves include *Paleoneilo* sp. and *Grammysia* sp.

Trace fossils are a distinctive feature of the rocks throughout the gully-cliff-roadcut, but the most striking traces are found in the cliff section (Figure 28). The ichnofossils include several types of *Cruziana*-type tracks probably made by an arthropod (Plate 7A, B, C), resting traces, and the burrowing traces *Teichichnus* and *Planolites* (Plate 7D, E, F). Higher in the section, small vertical burrows like *Skolithos* and *Trichichnus* are found. It is of interest to note that most of the beds in the cliff section do not contain vertical, feeding burrows, but instead the traces are those of tracks in the sand and mud.

Interpretation

This sequence represents deposition in marine environments increasingly encroached upon by prograding distributary lobes. The basal shale appears to have formed in a site of rapid mud deposition, perhaps in an interdistributary bay, because the brachiopods in the shale are only slightly disarticulated and the shales contain small, isolated load casts. The next higher beds are of greatest interest here and they most likely represent deposition on the seaward edge of a tidal shoreline. The evidence of current reversal, the lenticular bedding, the presence of shale chips and shell debris in the sandstones, and the intimately intercalated but clearly separated beds indicate alternations of deposition from traction and suspension in a situation where bottom scour is common. Lack of evidence for a well developed infauna of trace-forming animals suggests that time was not available between major deposition events for colonization of the substrate by burrowers.

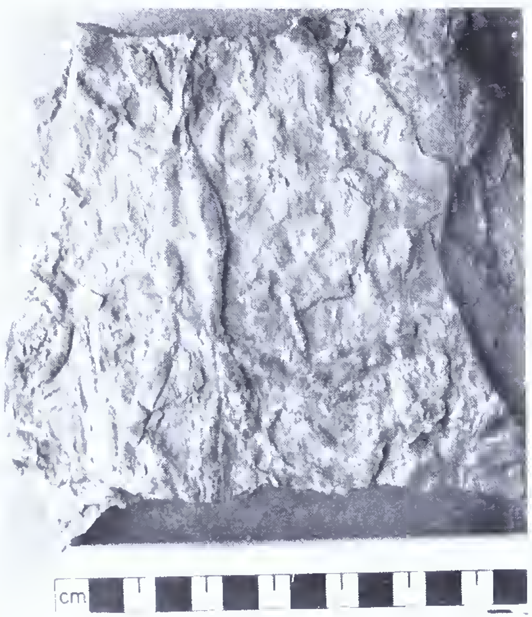
Deposition of the hematite-bearing sandstones also appears to require deposition in very shallow marine environments, perhaps tidally-influenced ones (Blatt and others, 1980, p. 603). If these units are, as they appear to be, the facies equivalents of the Mansfield iron ore (Stop 9, Day 2) then deposition must have taken place in shallow marine water along a "low energy, broadly embayed shoreline." (Van Houten and Bhattacharyya, 1981; Van Houten and Karasek, 1981). These authors feel that if the shoreline was tidal then the tide range was less than 2 m.



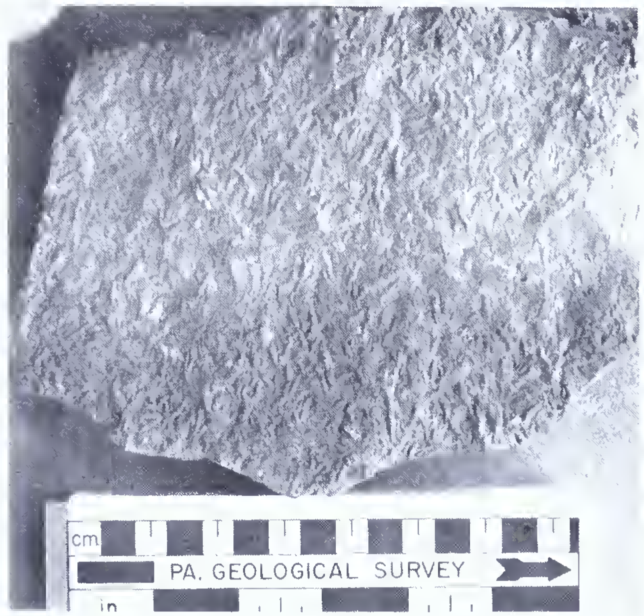
A. Meandering Cruziana from about 20 m, Figure 28.

B. Close-up of Cruziana showing endopodite markings; from below 20 m, Figure 28.

C. Close-up of Cruziana showing markings of pleurae and exopodites (upper right); from below 20 m, Figure 28.



D. Planolites from below 20 m, Figure 28.



E. Abundant small ?Planolites from below 20 m, Figure 28.

F. Planolites on crudely ripple-bedded surface of brownish-gray sandstone; from below 20 m, Figure 28.

PLATE 7

The burrowed and bivalve-bearing siltstones, shales and sandstones at the top part of the cliff section may represent the more shoreward facies of the sequence. Rocks exposed in the roadcut demonstrate marine environments nearly to the top of the sequence. There a fluvial channel sand was deposited on the bay muds and alluvial overbank deposits of the next lower units.

LEAVE STOP 3 and proceed west on PA Route 414.

0.6	60.9	Village of Franklindale.
0.4	61.3	TURN LEFT onto township road (08003) following sign to Sunfish Pond County Park.
0.1	61.4	Cross Towanda Creek. Outcrops of Lock Haven-Catskill Formation transition on right and left below bridge.
0.1	61.5	Hummocky glacial terrain on left.
1.8	63.3	TURN LEFT onto dirt road (Route 350) following sign to Sunfish Pond County Park. Start ascent of Barclay Mountain.
0.5	63.8	Numerous discontinuous outcrops of Catskill Formation occur in next 0.5 mile.
0.6	64.4	Small flagstone quarry at road side on left in Huntley Mountain Formation. Intermittent outcrops of Huntley Mountain along road above quarry include some red siltstone and shale.
0.4	64.8	Crossing contact between Huntley Mountain Formation and Burgoon Sandstone.
0.1	64.9	Small outcrop Burgoon Sandstone to the left.
1.0	65.9	CONTINUE AHEAD following sign for Sunfish Pond County Park. Road to left goes to strip mine operation of Jones and Brague Mining Co.
0.2	66.1	BEAR LEFT following sign for Sunfish Pond County Park.
0.5	66.6	Outcrop on right of Pottsville sandstone. Passing site of old town of Barclay.
0.5	67.1	BEAR RIGHT at road fork following sign for Sunfish Pond County Park; note piles of red-dog, burned-out culm on left--this material is used as road metal.
0.1	67.2	TURN RIGHT following sign to Sunfish Pond County Park.
1.8	69.0	Former site of old coal mining town called "Carbon."
1.6	70.6	BEAR LEFT onto paved road.

0.1 70.7 Small outcrop of Burgoon Sandstone on left.

1.0 71.7 Sunfish Pond County Park; BEAR LEFT following paved road around Pond. Note outcrops of basal Pottsville sandstone and conglomerate on left along road.

0.3 72.0 LUNCH STOP at pavilion at east end of Sunfish Pond. Pull beyond pavilion and circle on right side dirt roads. Basal Pottsville conglomerate exposed here will be discussed by W. E. Edmunds.

Pottsville Conglomerate

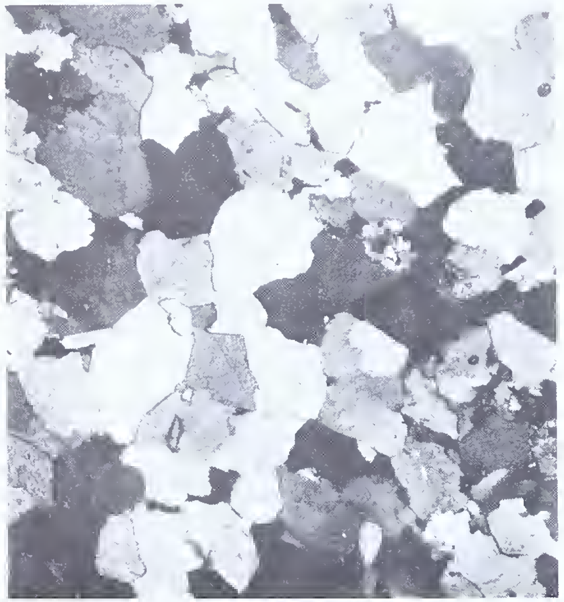
The basal Pennsylvanian Pottsville conglomerate and conglomeratic sandstone is well exposed near the pavilion on the east side of Sunfish Pond, located in a shallow depression in the broad top of Barclay Mountain. The Pottsville in this area is caught in a deep depression in the Barclay syncline, the axis of which lies about three-fourths of mile to the south of the pond. Because of the minable coal seams overlying the conglomerate, the top of Barclay Mountain is also referred to as the Barclay Coal Field.

The Pennsylvanian in this area rests disconformably on the Lower to Middle Mississippian (Osagian?) Burgoon Sandstone. The conglomerate zone is usually at or near the base of the Pottsville Formation and is widely present throughout north-central Pennsylvania. It is probably not quite a continuous sheet, but is a series of closely imbricated, overlapping conglomeratic lenses. There are sometimes other separate conglomerates somewhat higher in the Pottsville.

The conglomeratic zone at Sunfish Pond is 12 to 18 ft thick. It is conglomeratic sandstone, composed almost entirely of monocrystalline and polycrystalline quartz with authigenic silica cement (Plate 8-A). It classifies as a mature or supermature quartzarenite. Mobilization of silica by pressure solution has obscured most original grain boundaries. The grains are probably subrounded to rounded, although upon weathering the crystal faces of the silica cement may give a subangular appearance to the grains. Bedding is lensoidal or wedge-shaped and ranges from a few inches to several feet thick. Crossbedding is very common and includes numerous small planar bedded sets and large troughs 20 to 30 ft across (Plate 8-B).

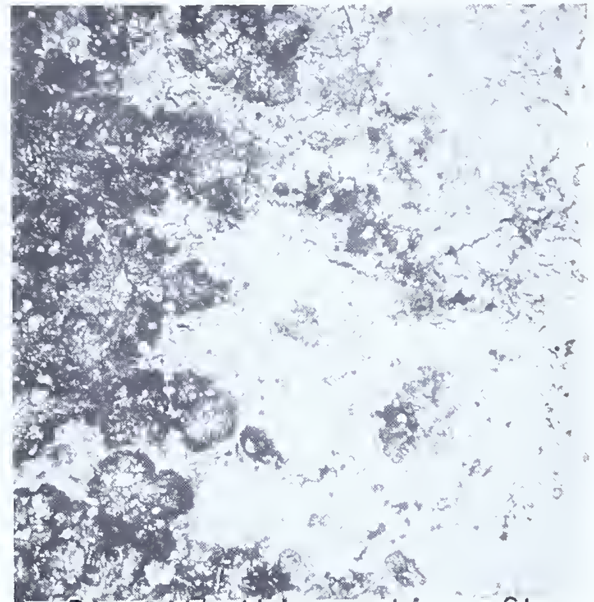
Preliminary crossbedding directional studies at the stop as well as elsewhere along the Barclay syncline in this area indicate that the source direction was from the southeast. This strongly suggests that the basal Pottsville conglomerates, including the one at this stop, are an extension of the Sharp Mountain Member of the Anthracite Pottsville, rather than the Olean Pottsville from the north. Using the customary correlations then, between the Pennsylvanian sections of the Anthracite and Bituminous areas of Pennsylvania (see section on Pennsylvanian correlations), it appears that the Pottsville conglomerate of the Barclay syncline may correlate with the uppermost Pottsville and lowermost Allegheny Groups of western Pennsylvania (Mercer and Brookville-Clarion coal complexes).

The stone seen at this outcrop closely resembles the basal Pottsville

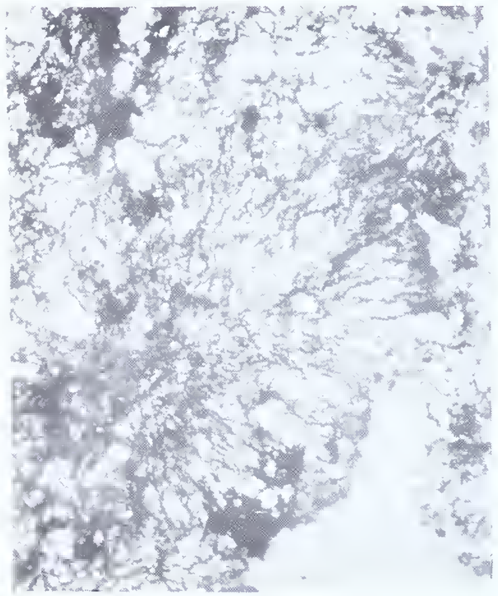


A. Pottsville quartzarenite; x28; crossed nicols.

B. Basal Pottsville conglomeratic sandstone, Sunfish Pond; looking up trough X-bed axis.



C. Pisolith thin section, Stop 6; note multiple nuclei; x 28; plane-polarized light.



D. Pisolith thin section; plumose structure = algae?; x79; plane-polarized light.

E. Pisolith thin section; calcite-filled syneresis fractures; x28; plane-polarized light.

F. Hypichnial ridges from bottom of tidal sandflat deposit; Stop 11b (15 m, Figure 36).

PLATE 8

sandstone presently being quarried north of Morris, Pennsylvania (near Stop 8). There, Warwick Silica Co. crushes the sandstone for foundry use and for glass plants.

LEAVE LUNCH STOP and retrace route to T-intersection with dirt road.

1.5	73.2	TURN LEFT onto dirt road.
0.8	74.0	Scattered outcrops of Huntley Mountain Formation between here and Stop 4.
0.3	74.3	STOP 4. Huntley Mountain Formation. Discussant: T. M. Berg. Parking is critical for buses at this stop. Pull-off space is on right of road above falls, and on left below falls. NOTE, please use extreme CAUTION in ascending the west side of the stream. The wet rocks are slippery, and several cliffs are quite high!

The strata exposed in these outcrops along the stream and waterfalls above the road (Figure 29) are in the lower part of the Huntley Mountain Formation of Berg and Edmunds (1979). This series of exposures in the streambed below Holcomb Pond is the type section of the Sunfish Formation of Woodrow (1968). The approximate upper half of the Sunfish is correlative with the Huntley Mountain Formation. Woodrow's section "PB" (1968), units 53 through 89 (top), are considered equivalent to most of the Huntley Mountain. Woodrow considered his unit 89 to be "Pocono", but it is included in the upper Huntley Mountain, statigraphically not far below the Burgoon Sandstone which is mapped (Berg and others, 1980) south and east of the Holcomb Pond at the top of Barclay Mountain. This section is also the "South Mountain" section of Williams and Kindle (1905, p. 105-106). Their units 10 through 29 closely approximate the interval mapped now as Huntley Mountain Formation; they applied the term "Oswayo" to this succession. Williams and Kindle's unit 30 interval (covered) probably contains the Huntley Mountain-Burgoon contact. The transitional nature of the Huntley Mountain between the underlying Catskill Formation and the overlying Burgoon Sandstone can be seen in the complete section ascending Barclay Mountain along the stream. Time during the Field Conference will allow examination of only the first 50 m of section above the road; therefore the similarities to the underlying Catskill will be emphasized. Five or six fining-upward fluvial cycles (Figure 29) may be seen, and participants are encouraged to discuss the following:

1. What defines fining-upward cycles here? Is it in fact, proper to describe these as "fining-upward cycles?"

2. How do these cycles differ from underlying Catskill cycles? (You may want to withold comment until Stop 5).

3. What is the significance of the greenish-gray coloration of Huntley Mountain sandstones, in contrast to the grayish red, brownish gray or medium gray of underlying Catskill sandstones?

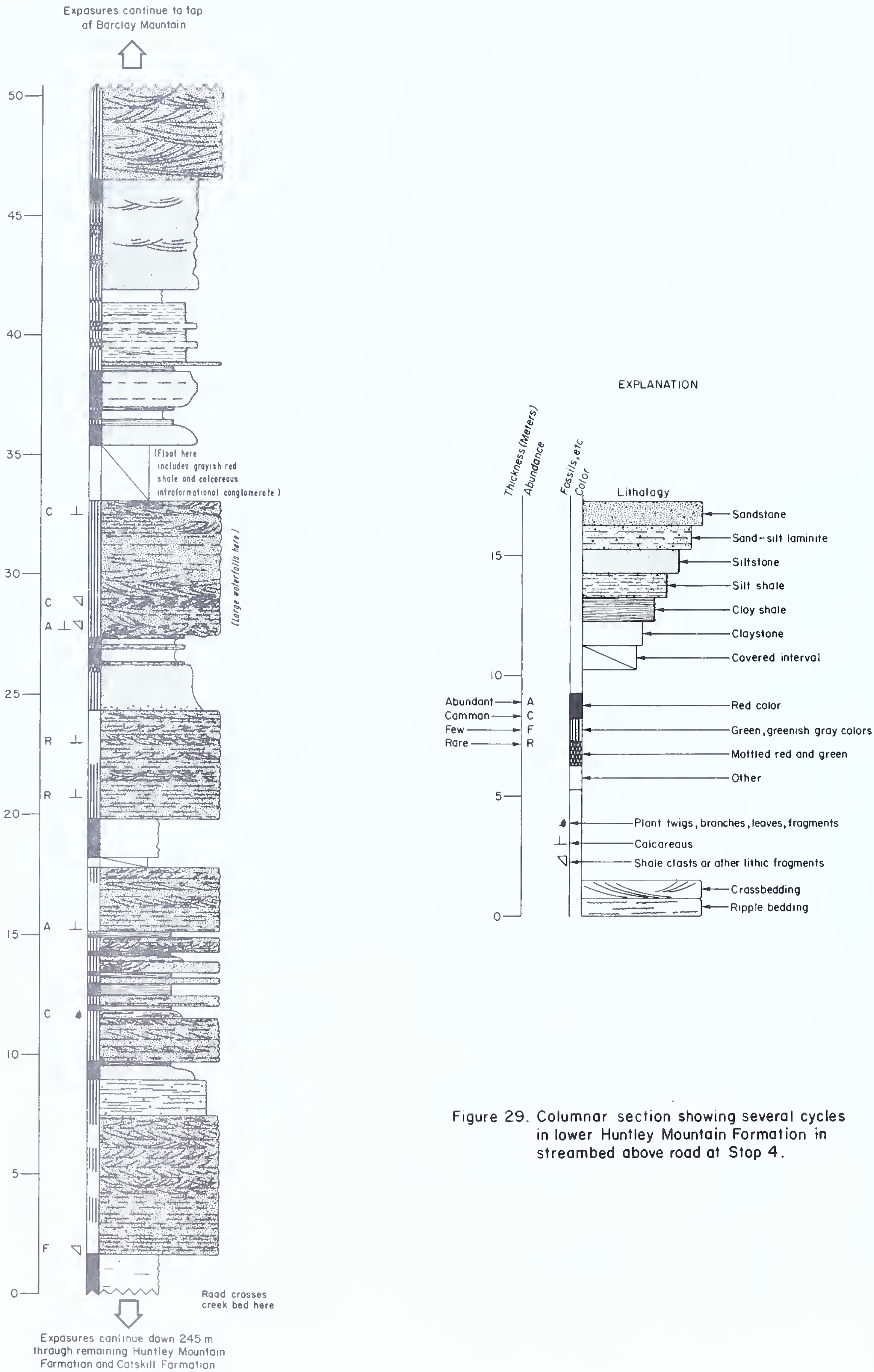


Figure 29. Columnar section showing several cycles in lower Huntley Mountain Formation in streambed above road at Stop 4.

4. Can any judgement be made on paleogeomorphology of Huntley Mountain fluvial systems in comparison with Catskill fluvial systems? More specifically, do Huntley Mountain cycles represent changed sinuosity of meander systems? Are Huntley Mountain meander systems more ephemeral than Catskill meander systems? Could this succession represent braided stream deposits?

5. For those who are familiar with the overlying Burgoon Sandstone: What do you think the depositional environment was for the Burgoon? How does your interpretation for the Burgoon differ from what you observe and interpret at this stop?

6. A question for tomorrow: Are factors controlling interpreted cyclicity here in <u>any way</u> comparable to factors controlling cyclicity interpreted for parts of the marine Upper Devonian (Stop 11)?

LEAVE STOP 4 and proceed ahead down hill. Several outcrops of Huntley Mountain sandstones on left.

0.3	74.6	Outcrop of red sandstone and shale of Catskill Formation on left. More outcrops ahead.
0.1	74.7	View straight ahead of the "Gulf Brook" section of Sherwood (1878), and Williams and Kindle (1905); this is also section PA of Woodrow (1968), and includes Wiscoy, Pipe Creek, and Nunda Formations, and the Corning Member of the Gardeau Formation.
0.6	75.3	STOP SIGN. CONTINUE STRAIGHT ahead on Mill Street.
0.3	75.6	STOP SIGN in town of Leroy. TURN LEFT onto PA Route 414 westbound. Between here and mileage 85.1, west of Canton, the route follows a glaciated valley typical of many in the area. The valley is broad and floored with an outwash plain which is large in comparison with the stream now occupying the valley. Valley sides comprise mixed till and ice-contact stratified drift deposits. Till tends to underlie the uniform, smooth slopes and sand and gravel the more irregular hilly areas, but topography alone is not adequate criterion for materials indentification. Deposits along the margins of the valley may be up to 10's of meters thick.
1.6	77.2	Village of West Leroy.
0.3	77.5	Good view of glaciated Towanda Creek valley on left.
0.2	77.7	Outcrop of Lock Haven Formation on right.
1.7	79.4	Small rounded hill on left below road level is a kame.
1.6	81.0	Large exposure of sand and gravel in a kame on right.
1.8	82.8	Borough of Canton.

0.6	83.4	Junction with PA Route 154. CONTINUE STRAIGHT ahead.
0.2	83.6	STOP LIGHT. TURN LEFT following PA Route 414 west.
0.7	84.3	View of kames ahead on right. Travelling on outwash plain.
0.8	85.1	TURN RIGHT following PA Route 414 west. The route between here and mileage 112.8 at Morris will traverse glaciated upland topography. Slopes are generally smooth and irregularly-shaped constructional topography is minimal. Till is the main glacial deposit. Till thickness is variable, but generally thin.
1.5	86.6	Outcrops of Catskill Formation on both sides.
1.8	88.4	BEAR LEFT at cross road following PA Route 414 west.
2.6	91.0	Village of Ogdensburg.
3.1	94.1	Liberty township line.
5.3	99.4	Borough of Liberty.
0.1	99.5	STOP SIGN. TURN LEFT following PA Route 414 west.
0.3	99.8	TURN RIGHT following PA Route 414 west.
0.7	100.5	Pass under U. S. Route 15 and TURN LEFT onto U. S. Route 15 south.
0.9	101.4	Road overpass.
0.2	101.6	Lycoming County line.
0.2	101.8	STOP 5. Catskill Formation. Discussants: W. D. Sevon and H. A. Pohn. Buses will proceed south on U. S. Route 15 and exit for Buttonwood Junction and PA Route 284. Turn left onto PA Route 284, return to U. S. Route 15 north, return to Stop 5, and park on berm on right side of road.

The rocks exposed here are in the upper part of the Catskill Formation and comprise sandstones, siltstones, and shales interpreted to have originally been sediments deposited by meandering streams which wandered across the alluvial plain part of the Catskill clastic wedge. A complete fining-upward cycle occurs in the southern and central part of the exposure. These gray, cross-bedded sandstones are separated by an erosional contact from underlying siltstones, the top of a lower cycle. The gray sandstones grade upward into grayish red sandstones which are in turn replaced by red siltstones and claystones. Another erosional contact overlain by gray, cross-bedded sandstone marks the start of another cycle. The gray sandstones presumably represent channel deposits and the red siltstones and claystones represent overbank floodplain deposits.

The northern part of the exposure (Figure 30) is possibly unique in exposures of the Catskill of Pennsylvania and is interpreted to represent a filled cut-off meander. The fining-upward cycle present in the southern and central parts of the exposure has been completely or nearly completely eroded (Figure 30, A-B). The eroded channel is filled with a variety of thin bedded sandstones, siltstones, and claystones. Numerous scour (erosional) surfaces occur. Root traces, some plant remains, fish plates, an aestivation burrow, and calcareous nodules are present. Very thin fining-upward cycles reminiscent to some degree of turbidites occur, particularly in the center of the exposure (center of B-C, Figure 30).

The scenario envisioned here is as follows: The fining-upward cycle exposed in the southern and central part of the road cut was deposited by channel migration and overbank deposition. The depositing stream meandered and eroded these previously deposited sediments to create a new channel. A meander cut-off occurred and the eroded channel was left initially as an ox-bow lake. Periodic flooding deposited sediment below water level in the lake and the gray sediments at the base of the fill sequence represent these deposits. Eventually the lake dried out. Continued periodic flooding created temporary lake conditions and allowed deposition of the turbidite-like sediments (rhythmites?). Following flooding the lake dried and occasionally some plants established themselves on the muddy surface and roots sometimes penetrated through several layers of sediment. The next flood event destroyed the plants. Oxidation altered the sediments to red color. Fish carried into the temporary lake either died or burrowed into moist mud and waited for the next flood and a chance to escape. Some floods were relatively quiet and resulted in deposition only. Other floods were more severe and erosion occurred prior to deposition. Calcareous nodules developed elsewhere as caliche in near-surface parts of the floodplain muds were occasionally eroded, swept into the gradually filling channel, and deposited as basal gravels. Eventually the cut-off channel was filled and normal channel migration resulted in deposition of sandstone at the base of the next fining-upward cycle.

This outcrop has several apparent faults, both normal and thrust, which probably resulted from stress release when the roadcut was excavated. A joint set within the underlying sandstone has a westerly dip of 40°+. In the shaly intervals above the sandstone beds, this joint set commonly has slickensides that have a strike of N60E and a dip component down the joint face. The direction of movement along these joints gives the appearance of normal faulting but is probably due to the overburden pressures extruding the shaly units down the joint face and out into the roadcut.

Approximately 30 m south of the north end of the outcrop is an apparent synthetic thrust fault that has a displacement of 15 cm. Although the thrust appears to be directed northward, the slickensides have a strike of N60E, which is the same as that of the apparent normal faults.

In the sandstone sequence below the shaly sequence, blasting drill holes have been offset since the highway was constructed. These holes are generally offset toward the road, and some holes show offset in a N60E direction.

LEAVE STOP 5 and proceed north on U. S. Route 15.

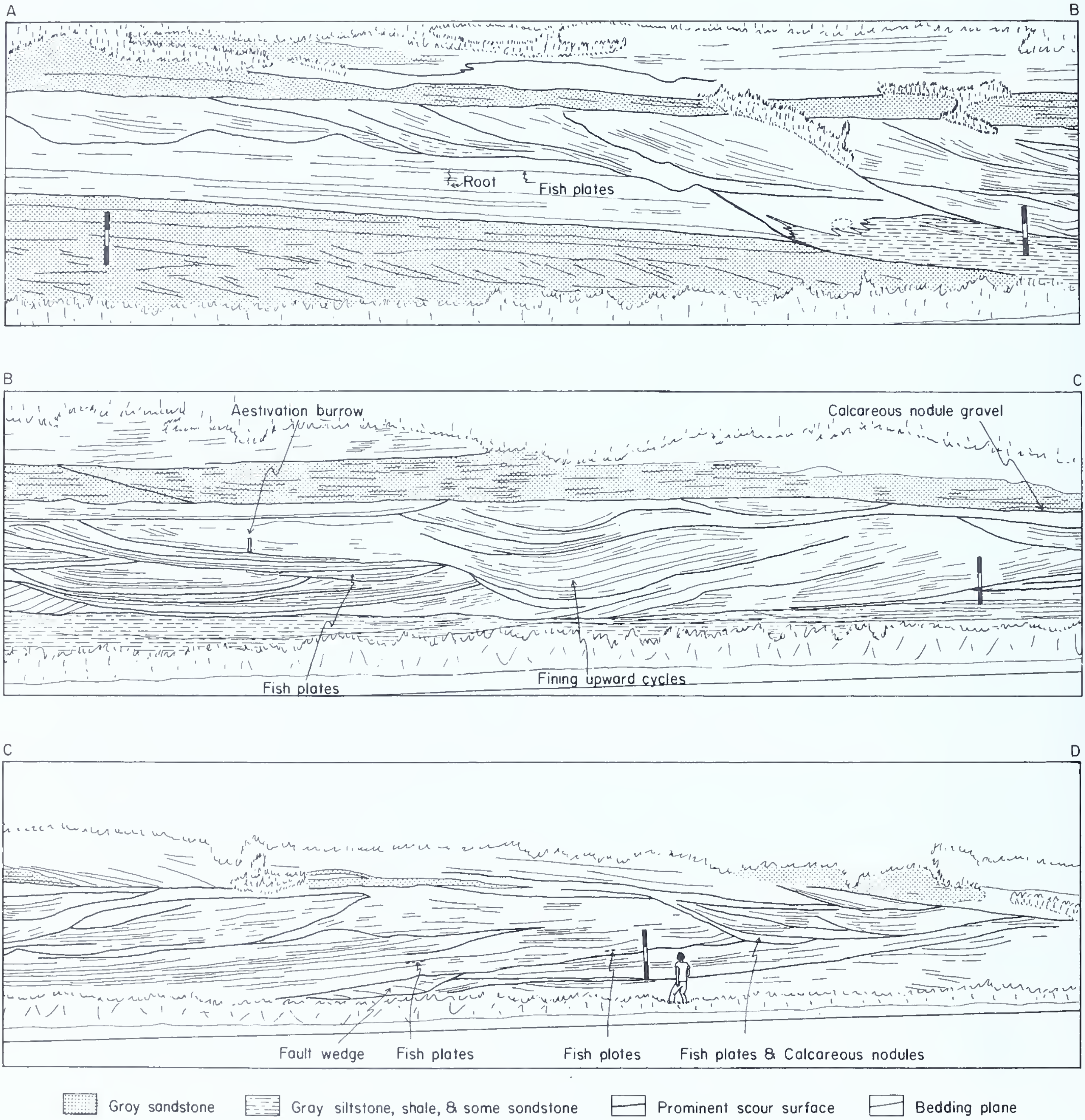


Figure 30. Exposure of Catskill Formation on west side of U.S. Route 15, near Liberty, Pennsylvania. All rocks are red in color except those otherwise designated. Scale divided into 50 cm intervals.

0.2	102.0	Tioga County line.
0.7	102.7	EXIT RIGHT to PA Route 414.
0.3	103.0	STOP SIGN. TURN LEFT onto PA Route 414 west.
2.9	105.9	BEAR RIGHT at road fork following PA Route 414 west.
6.9	112.8	STOP SIGN. Village of Morris. CONTINUE STRAIGHT ahead onto PA Route 287 north (PA Route 414 west bears left).
0.1	112.9	Crossing Babbs Creek.
0.2	113.1	Crossing Wilson Creek. Channelized stream bed and acid mine water on both sides.
1.2	114.3	Crossing Basswood Run which carries acid mine drainage from Hunters drift with a pH of 3.2 in June. This is the old bache mine.
1.4	115.7	Delmar township line.
0.3	116.0	STOP 6. Huntley Mountain Formation, pisolite locality. Discussant: T. M. Berg. Park on right berm opposite Anna S. road on left.

These outcrops (Figure 31) in the bed of Wilson Creek are within the Huntley Mountain Formation, and are approximately 85m (280 ft) below the base of the Burgoon Sandstone. Of particular interest here is a thick pisolite bed in close association with contorted sandstone and siltstone beds. Other outcrops in the creek bed include: (1) crossbedded sandstone containing abundant fossil plant fragments and fossil tree branches or trunks and pyrite balls; (2) sandstone having sinuous to linguoid ripple marks; and (3) greenish gray, trough crossbedded sandstone typical of the Huntley Mountain.

Individual pisoliths in the pisolite bed range grom 0.5 to 4.0 cm in diameter and usually display internal concentric laminar structure. The pisoliths are randomly mixed with shale clasts and other lithic fragments, along with fossil plant fragments. The whole mixture is set in a sandy, muddy, calcareous matrix. Some of the shale clasts are up to 20 cm long. The pisolite bed is poorly bedded, massive, and has a lumpy appearance.

The pisoliths are spherical to botryoidal in shape. Thin sections of the pisoliths reveal a complex of irregular radiating sparry calcite layers commonly containing quartz silt and sand grains. In general, the pisoliths appear to have grown by accretion around a common nucleus, but the nucleus is vague and not easily delineated. Many pisoliths appear to have multiple nuclei (Plate 8C). Some pisoliths are poorly laminated and appear to be composed of micrite which has a vague "wormy" texture. Some of the nuclei have radiating plumose structure which is suggestive of the structure of filamentous algae (Plate 8D), but the reality of algal identification remains doubtful until detailed research is done. Many pisoliths display

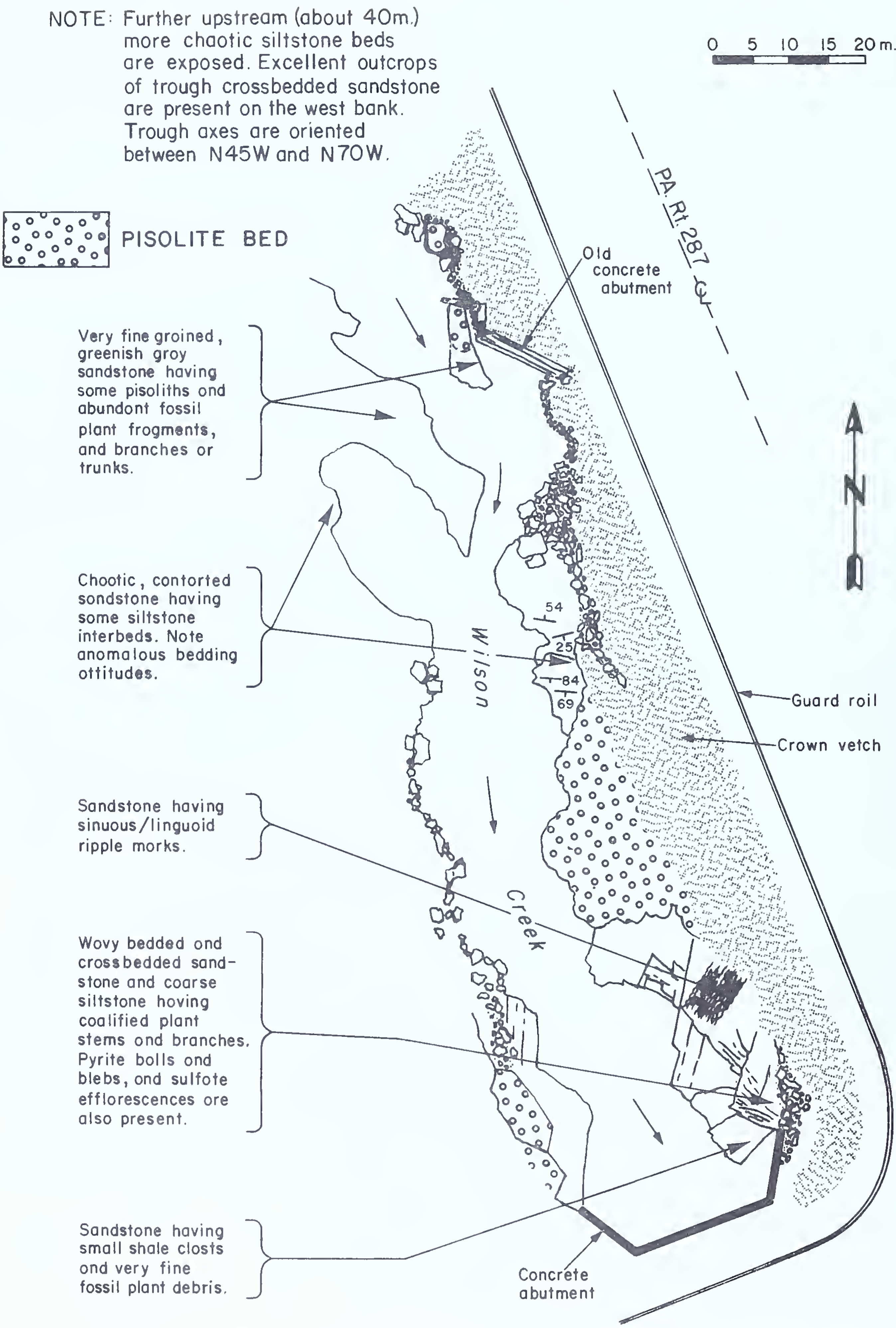


Figure 31. Map showing location of pisolite bed at Stop 6.

internal syneresis fractures which are filled with sparry calcite (Plate 8E). The pisoliths often have limonite intergrown with the calcite, and weather to a yellowish brown.

McGannon (1975) documented the occurrence of oolites and pisolitic calcareous conglomerate in Late Pleistocene fluvial sediments in south central Texas. He concluded that the freshwater oolites were formed by both physio-chemical and biological processes. The carbonate was thought to have been derived from an underlying older calcareous stratum, and brought to the surface by artesian springs. Precipitation of the carbonate was also considered to have been facilitated by the action of algae. Collinson (1978, p. 65) explains that calcium carbonate may be precipitated in temperate lakes if calcareous rocks occur in the catchment area. He further states that macrophytic plants growing in marginal areas precipitate low-Mg calcite on stems, which is eventually included in surface sediments. Blue-green algae are also important in precipitation of calcium carbonate.

The following origin for the Huntley Mountain pisolite bed at this stop is suggested: While through-flowing low-sinuosity streams were carrying sandy sediments in established channels, interfluve areas saw the development of temporary freshwater ponds or small lakes. These bodies of standing water may have formed as cut-off channels or oxbow lakes (compare with discussion for Stop 5). Growth of blue-green algae and marginal macrophytes may have aided in the precipitation of calcium carbonate, while pre-existing calcrete or caliche within soils formed on surrounding overbank muds contributed calcium carbonate by slow erosion on pond or lake margins. Moderate agitation of the standing water gave rise to spheroidal pisoliths forming by both physio-chemical and biological processes. Eventual lateral migration of a major fluvial channel breached the ponded area and the pisolith-bearing sediment slumped as a semi-coherent mass into the channel and became part of the basal portion of the coarse member of a fining-upward fluvial cycle. The evidence for slumping and soft-sediment deformation is seen in the contorted sediments beneath the pisolite bed at this stop. The pisolite bed, contorted sediments, and large plant fragments, were buried rapidly by trough crossbedded sands of the through-flowing stream system.

Pisolite beds occur locally at the bases of fining-upward cycles elsewhere in the Huntley Mountain Formation, especially in the lower half of the formation. Similar pisolite beds have been observed in the Catskill Formation in north-central and northeastern Pennsylvania. The same relationship of pisolite to laterally-equivalent slump structures and contorted bedding have been observed in Catskill fluvial cycles.

Other interpretations for this unusual lithology will gladly be entertained at this stop.

LEAVE STOP 6 and CONTINUE north on PA Route 287.

0.1	116.1	Road to Antrim coal mines, and Blossburg coal historical marker on right.
0.8	116.9	Outcrop of Huntley Mountain Formation on right.

0.9	117.8	Gas well on right was drilled by Fairman Drilling Company of Dubois, PA, for Consolidated Gas Supply Corporation of Clarksburg, WV. Well located at elevation 1417 ft, 1500 ft south of lat. 41°41'N, and 4650 ft west of long. 77°17'30"W in the Antrim quadrangle. The Oriskany Sandstone occurred at 6428 ft and was 33 ft thick.
3.4	121.2	View ahead of a through valley, a former glacial lake spillway.
1.4	122.6	Nessmuk Recreation Area on left.
0.6	123.2	Borough of Wellsboro.
1.1	124.3	STOP LIGHT. TURN RIGHT following PA Route 287 north.
0.1	124.4	Penn Wells Hotel. End of Day 1.

ROAD LOG AND STOP DESCRIPTIONS
(Route map on inside of back cover)

DAY 2

Saturday, 3 October, 1981

Inc. Mil.	Cum. Mil.	Description
0.0	0.0	LEAVE front of Penn Wells Hotel and proceed west on PA Route 660.
1.2	1.2	Outcrop of Lock Haven Formation on right.
1.1	2.3	Outcrop of Lock Haven Formation on right.
0.3	2.6	Peak of Mt. Nessmuck at 3 o'clock. Nessmuck was the pen name of George Washington Sears who spent most of his outdoors time in the Pine Creek Valley.
0.3	2.9	TURN LEFT following PA Route 660 west at Junction with PA Route 362.
2.0	4.9	TURN LEFT at T-intersection following PA Route 660 west.
0.4	5.3	BEAR RIGHT at road fork.
1.1	6.4	STOP SIGN. TURN RIGHT following PA Route 660.
1.0	7.4	TURN LEFT at road fork following PA Route 660.
0.7	8.1	White tower at 10 o'clock is the Omni station for the Chemung County Airport.
1.2	9.3	TURN RIGHT at crossroads following PA Route 660.
0.6	9.9	BEAR LEFT at road fork.
0.7	10.6	Entrance to Leonard Harrison State Park.
0.2	10.8	STOP 7. Pine Creek Gorge, the Grand Canyon of Pennsylvania. Discussant: G. H. Crowl.

The Pine Creek Gorge (cover) is a deep, narrow canyon cut into Upper Devonian rocks, partially by pre-Pleistocene headward erosion, partially by glacial meltwater, and partially by drainage diversion effected during several Pleistocene ice advances (see pages 42-44 for complete discussion). Crossbedded, gray sandstones of the Catskill Formation are exposed in the overlook area and some red beds can be viewed on opposite canyon walls. Marine siltstones and shales of the Lock Haven Formation are exposed near river level in the canyon.

The Turkey Track (for interested turkeys) affords a pleasant walk to Pine Creek (and can be done round trip in 40 minutes by the physically fit who stop to look at nothing). The excellent trail provides a good look at some of the Catskill Formation, particularly at a waterfall near the base of the unit, and the thinness of debris on the valley slopes. The Lock Haven Formation is well exposed along the railroad tracks at the bottom of the trail, and is very fossiliferous.

LEAVE STOP 7 and retrace route along PA Route 660.

1.5	12.3	TURN LEFT at crossroads following PA Route 660 east.
1.2	13.5	TURN RIGHT onto unpaved Martin Road (Route 416).
0.4	13.9	TURN LEFT at T-intersection.
0.6	14.5	TURN RIGHT at T-intersection onto paved road.
0.6	15.1	TURN LEFT onto unpaved Kennedyville Road (T 399).
0.4	15.5	Small quarry in Catskill Formation on left.
0.3	15.8	TURN RIGHT at T-intersection onto unpaved road.
0.2	16.0	BEAR LEFT at road fork onto N. Lawton Road (T 387).
0.3	16.3	BEAR RIGHT at road fork onto S. Lawton Road (T 385).
1.3	17.6	STOP SIGN in village of Stony Fork. TURN RIGHT onto paved road.
0.4	18.0	Sherwood (1878) reports that a salt well 300 feet deep was drilled on the west bank of Stony Fork Creek. The well was at the site of an old salt lick, and free flowed a 2 in. stream.
0.2	18.2	Village of Draper limits.
0.1	18.3	TURN LEFT onto unpaved route 58012.
0.5	18.8	BEAR RIGHT at road fork.
0.4	19.2	TURN LEFT at road junction.
0.4	19.6	Start of discontinuous outcrops of Huntley Mountain Formation on right marks approximate base of the formation.
0.6	20.2	BEAR RIGHT at road junction. Float of Burgoon Sandstone in woods on both side.
0.2	20.4	BEAR RIGHT at road fork.
1.2	21.6	Entrance to Rattler Mine on right.

0.2	21.8	BEAR LEFT at road fork.
1.5	23.3	CONTINUE STRAIGHT ahead at crossroads. This section of road is subject to change with changing mining conditions.
0.1	23.4	Road to left leads to Hunters drift.
0.1	23.5	Reclaimed coal strippings to right.
0.1	23.6	STOP 8. Antrim Mining, Inc., Anna S. Mining Complex. This is private property and permission to enter mining operations must be obtained. Discussants: T. M. Berg, W. E. Edmunds, P. B. Luce, G. H. Crowl, W. D. Sevon.

Coal Geology

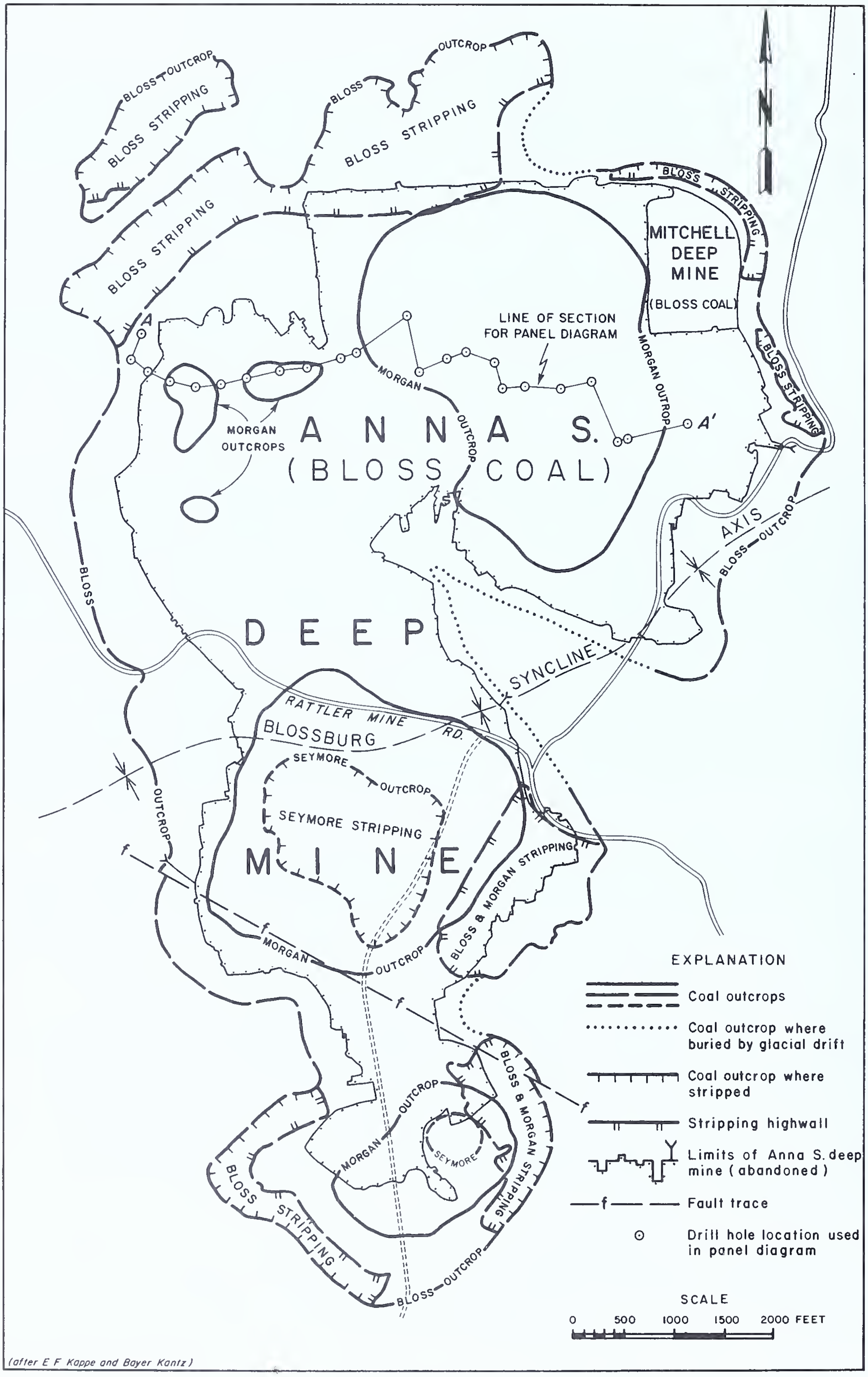
This stop is at the Anna S. coal mining complex operated by Antrim Mining, Inc. of Antrim Pennsylvania. Because active coal mining operations move continuously from one part of the property to another and progress is affected by mining conditions, environmental and permitting regulations, and other factors, it is difficult to anticipate what will be the exact nature and location of exposures at the time of the field trip. It is expected that a strip mine on the Morgan coal and possibly another on the Bloss coal will be open for the field trip.

The Anna S. mining complex (Figure 32) is located near the western end of the Blossburg-Antrim Coal Field which is located within the Blossburg syncline. Aproximately 230 ft of Pennsylvanian rock is preserved, including 100 ft of basal sandstone and conglomerate sandstone and 130 ft of overlying section from the Bear Creek coal to just above the Seymore coal (see Figure 7).

Several coal seams are present in the Anna S. area, at least 4 of which are or were economically valuable. The Seymore coal is the stratigraphically highest seam and originally underlay 2 of the higher knobs in the southern part of the property. The Seymore was reported to be 20 to 30 in. thick, but has now been almost entirely removed by strip mining.

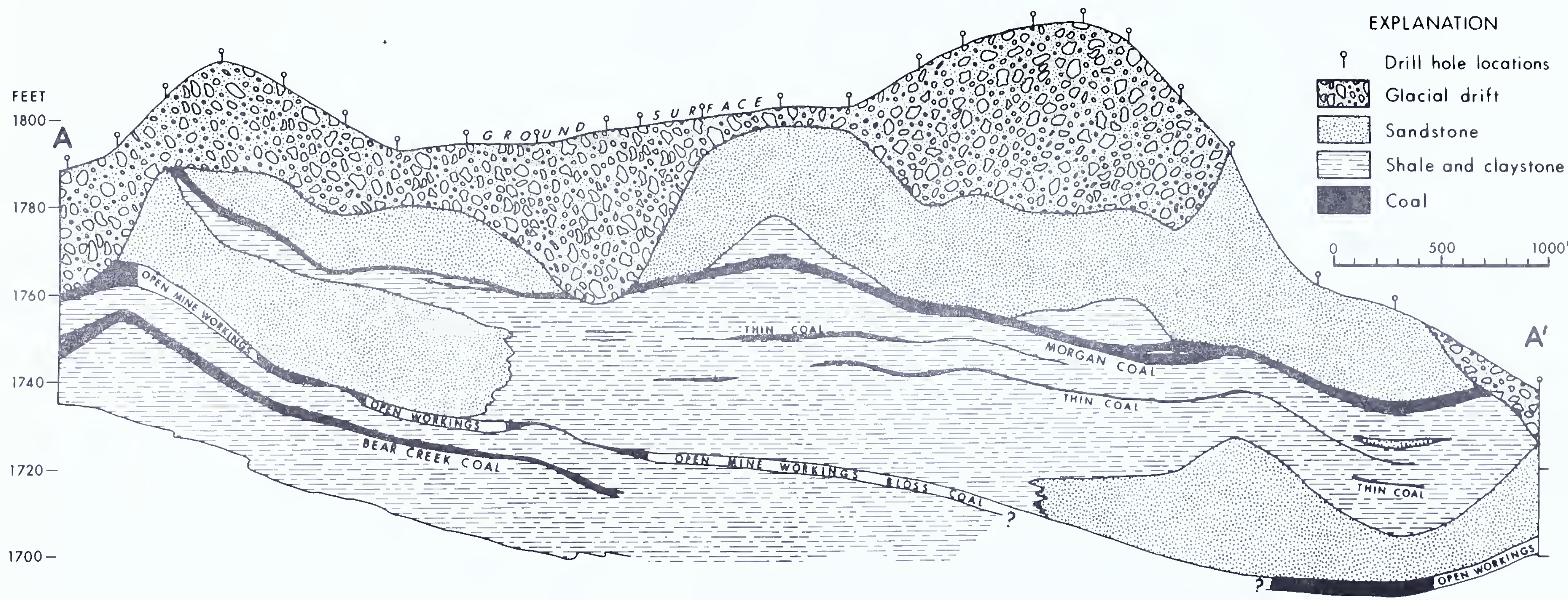
Approximately 50 ft below the Seymore is the Morgan coal which is a few inches to 3 ft thick. Available analyses show that the Morgan coal has a sulfur content between 0.5 and 1.75 percent and an ash content between 15 and 28 percent (as received basis). Because of the high ash content, it has a relatively low heating capacity of between 10,500 and 12,500 Btu/pound. Although the Morgan has been mined only to a very limited extent, its relatively shallow surface cover should render it widely accessible to stripping. For this reason, the seam probably has the largest mineable reserves on the property.

The Bloss coal was originally the best and most important bed on the Anna S. property. The seam reportedly varies from 24 to 55 in. thick. It is apparently very good quality coal, with most analyses showing sulfur content between 0.5 and 1.0 percent and ash between 14 and 19 percent on



(after E F Kappe and Bayer Kantz)

Figure 32. Antrim Mining, Inc., Anna S. mining complex, Morris, Pa.



Cross section A-A' across Anna S. mining complex.

as an as-received basis. An old analysis from the U. S. Bureau of Mines gave the sulfur as 2.9 percent and ash as 12.5 percent. Heating value is between 11,400 and 12,900 Btu/pound, as received.

The Bloss has been extensively deep mined or stripped throughout the property (Figure 32). The original Anna S. deep mine on the Bloss coal was opened in the late 19th century by the Fall Brook Coal Co. and closed in 1937. The coal produced from the deep mine was transported across the valley of Wilson Creek to Antrim by a cable bucket line (Plate 2, B). Prior to the opening of the Anna S., the small Mitchell deep mine was operated on the Bloss in the northeast corner of the property.

Since the closing of the Anna S. deep mine, a number of strippings have been conducted around the periphery of the Bloss outcrop. The most recent of these, in the northwest corner of the area, was closed in the spring of 1981. Prior to final backfilling, the following detailed section was obtained from the highwall exposure:

			feet
14.	Glacial till		20.0
13.	Sandstone, grayish orange and pale reddish brown, fine-to-medium-grained, very thin bedded, stongly weathered		3.0
12.	Claystone, light olive gray and brown gray, hacky to rubbly fragments, weathered		2.5
11.	Coal, very weathered		0.6
10.	Underclay, light gray, soft, abundant rootlets, weathered		0.5
9.	Clay shale to claystone, dark gray and grayish black to medium gray upward, abundant plant fragments, hackly		4.5
8.	Coal	0.25	1.2
	Clay shale, grayish black, hackly	0.35	
	Bone coal	0.2	
	Coal	0.2	
7.	Upward gradation of siltstone, medium gray to silty claystone, medium gray to claystone, medium gray to clayey siltstone, medium dark gray to claystone, grayish black; generally a fining-upward sequence; abundant plant fragments		7.3
6.	Sandstone, medium light gray, very fine-grained, micaceous, some carbonaceous fragments, 1-in. to 10 in. beds, blocky to slabby fragments, cross-bed sets up to 6 in. thick, silty in top 0.5 ft		5.8
5.	Sand-silt laminite, dark gray and light gray laminae, 1 to 5 mm sand laminae, 0.5 mm silt laminae, very fine-grained sand to coarse silt, well-developed ripple bedding and flaser/lenticular bedding, some plant fragments and black carbonaceous laminae		18.0
4.	Clay shale, medium gray grading up to light gray, fissile to sub-fissile, chippy, fairly soft, gradational bottom contact		0.5

				feet
3.	Clay shale, black to grayish black, thinly laminated, fissile, chippy and flaky, thin vitrain laminae, abundant plants			0.65
2.	Coal	0.70	coal analyses on page 74	4.1
	Carbonaceous shale parting	0.05		
	Coal	1.15		
	Hackly claystone parting	0.05		
	Bony coal	0.20		
	Hackly, carbonaceous claystone parting	0.05		
	Coal	1.50		
	Carbonaceous clay shale parting	0.20		
	Coal	0.20		
1.	Medium-dark-gray, nonfissile underclay			0.2 +

The Bloss has no further potential for deep mining. It is likely that it can be partially stripped along the west side of the property. The extent of additional stripping is limited in part by the proximity of the edge of the old Anna S. deep mine to the outcrop. Acid mine drainage considerations mitigate against stripping into old underground works unless a very large area can be stripped out. This, in turn, requires that a substantial part of the original coal must still be in place in the form of mine pillars.

The Bear Creek coal is apparently a fairly persistent bed which lies between 5 and 12 ft below the Bloss. Its thickness is usually between 9 and 24 in. A single analysis of the Bear Creek gives an ash content of 10.37 percent and sulfur content of 2.81 percent. The thermal potential is 13,358 Btu/pound.

The Bear Creek is so closely associated with the overlying Bloss, that it can be treated as almost a part of the Bloss coal complex.

For the most part the Bear Creek can be considered mineable only where the Bloss can still be mined. It is too thin to mine underground, but can be readily stripped with the overlying Bloss coal.

The coal extracted from the Anna S. mine is delivered to the New York State Electric and Gas Corporation for use in electric power generation.

Depositionally, the Bloss-Bear Creek coal complex represents a widespread, low energy swamp environment. After the initial deposition of the plant material which formed the Bear Creek coal, a massive influx of sediments was introduced by a period of flooding in which the natural protective confines of the swamp were temporarily destroyed, and large amounts of clastics were brought into the swamp basin.

That this was not a permanent destruction of the swamp environment is indicated by the rapid reestablishment of the widespread Bloss coal swamp which was sustained for a period sufficiently long to deposit enough peat to produce 3 to 4½ ft of coal.

Eventually, however, the levees or whatever feature protected and confined the Bloss swamp were breached again. This time in sustained fashion. A maze of anastomosing distributary streams was established across the area represented by the thick sandstone bodies above the coal.

Laterally, between these sandstones, sections made up of finer-grained siltstones, shales, sand-silt laminites, and coals of limited extent were deposited. Lenticular and flaser bedding is common in these finer grained deposits. They probably represent the levee deposits adjacent to the main distributary streams and also interfluvial overbank deposits, lakes, and small swamps.

This distributary system was eventually abandoned in this area and a new swamp formed in which the plant material which became the Morgan coal collected. This in turn was destroyed and buried when rivers again broke into the area and reestablished new channels, levees, and interfluvial zones represented by the sandstones and other sediments overlying the Morgan coal.

The overall depositional environment reflected in the sediments exposed in the Anna S. mining area is that of a supratidal deltaic distributary system, commonly referred to an upper delta plain situation. It is probably the upper part of one of the deltas fringing the marine to brackish embayment which penetrated into western Pennsylvania during the early DesMoinesian Epoch.

Glacial Geology

Strip mining for coal during the spring and summer of 1981 by Antrim Mining Company exposed a sequence at present unique in the eastern glaciated part of Pennsylvania. Prior to the excavation of this strip mine no exposures of multiple tills were known in Pennsylvania east of the Salamanca reentrant (the area where the glacial boundary in Pennsylvania goes north into New York state leaving an area of presumably unglaciated terrain between the eastern and western glaciated areas).

The vertical sequence temporarily exposed here (Figure 33) revealed three color distinctive tills: an upper brown till, a middle yellow till, and a lower gray till. The brown till has a damp color of reddish brown (5YR4/3-4/4) to brown-dark brown (7.5 YR 4/2); the yellow till, yellowish red (5YR5/6); and the gray till, dark gray (5YR4/1). These tills dry to brown (7.5YR4/4-5/4), light to strong brown (7.5YR6/4-5/8) to yellow (10YR7/4-7/6), and grayish brown (10YR5/2) respectively. Lithologies of the different tills (Table 10) are not significantly different. Striated pebbles are common in the brown and gray tills. All pebbles in the yellow till are weathered and usually have a yellowish coloration. Grain size composition of the tills (Table 11) likewise shows little difference between the tills. Organic carbon determinations indicate that the gray till has 1.84 percent organic carbon and the brown till has 0.97 percent organic carbon.

The contact between the brown till (upper) and yellow till (middle) is apparently an erosional contact with evidence of local mixing of the two tills and evidence of local inclusion of masses of the yellow till in the

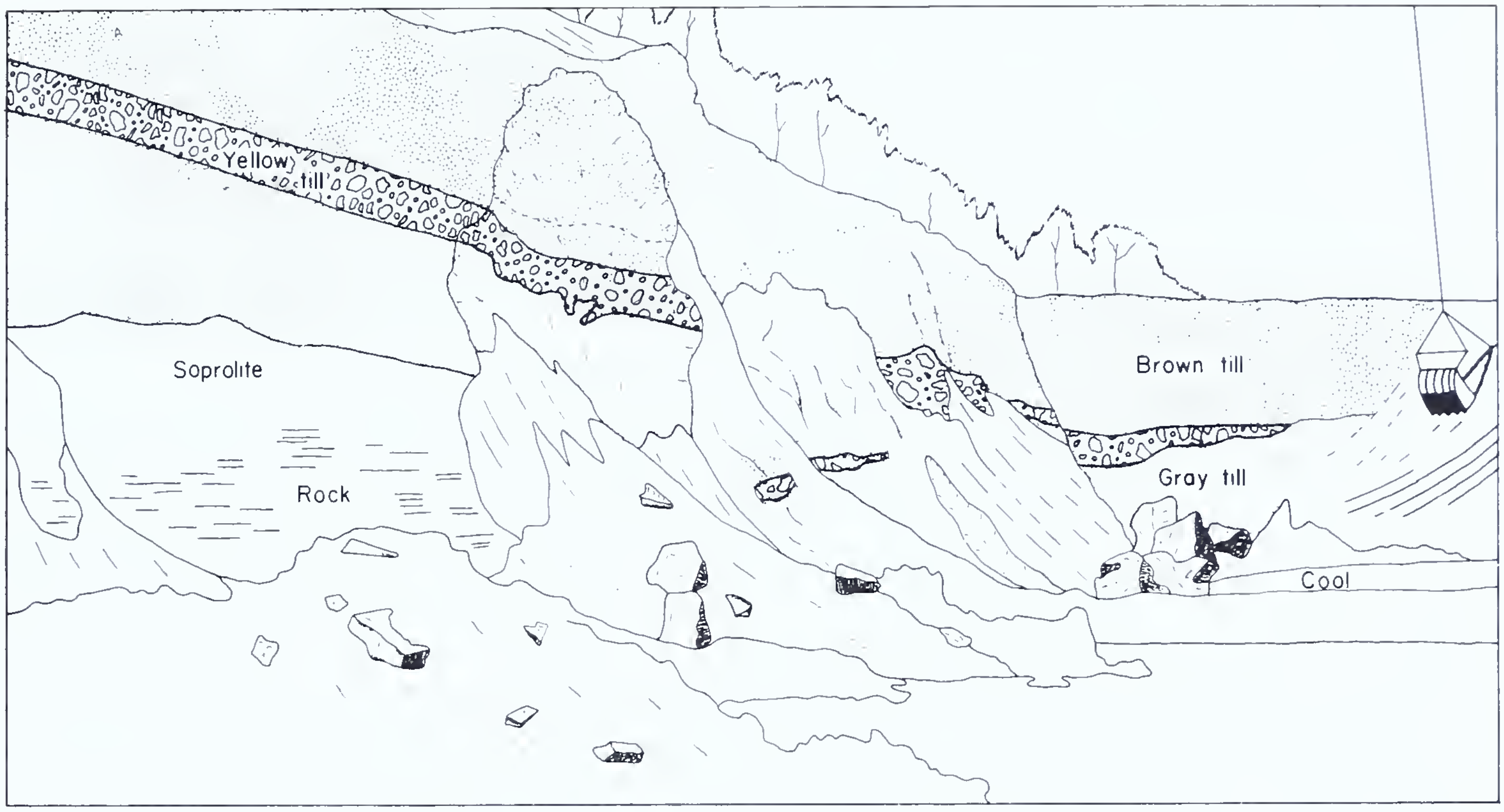


Figure 33. Exposure of multiple tills in formerly exposed strip mine of Antrim Mining, Inc., Morris, Pennsylvania. Schematic diagram was assembled from photographs of the exposure.

Table 10. Pebble lithology composition of tills at Antrim Mining, Inc., strip mine, Morris, Pennsylvania.

Pebble Lithology (4-64 mm)	Till Composition (in percent)		
	Brown (14 samples)	Yellow (6 samples)	Gray (4 samples)
Gray sandstone	72	78	65
Red sandstone	1	3	T
Gray siltstone	15	1	17
Red siltstone	5	T	3
Gray claystone	2	7	9
Red claystone	T*	1	1
Quartz	4	4	T
Iron-cemented fragments	1	6	2
Coal	T	0	2
Coaly shale	T	0	0

*T - trace

in the brown till. The contact between the yellow till (middle) and the gray till (lower) is sharp and shows no signs of mixing.

The upper brown till has a well developed fragipan (a very compact, silt/sand rich horizon, sometimes with iron accumulation, which interferes with root and water penetration) in the soil zone. Soil development,

Table 11. Grain size distribution (in percent), liquid limit index, and plasticity index of till samples from Antrim Mining, Inc., strip pit, Morris, Pennsylvania.

	Property	Till: Brown (14 samples)	Yellow (6 samples)	Gray (4 samples)
Grain size	2 mm	22.1* (4.8)**	21.4 (6.1)	26.2 (5.2)
	2 - 0.42 mm	9.0 (2.6)	8.5 (2.1)	8.2 (1.5)
	0.42 - 0.074 mm	21.8 (2.3)	24.7 (4.2)	22.1 (0.9
	0.074 - 0.005 mm	32.9 (4.3)	30.4 (3.0)	29.4 (2.9)
	0.005 mm	14.2 (2.0)	15.1 (1.7)	14.1 (2.5)
	Liquid Limit	20.6 (1.1)	21.7 (3.5)	20.7 (1.7)
	Plasticity Index	4.6 (1.6)	5.0 (2.4)	2.8 (2.2)

*Mean ** Standard deviation

including the fragipan, appears typical of soils in Pennsylvania which are developed on glacial tills of Woodfordian (Late Wisconsinan) age. The color and weathering of the yellow till is typical of tills identified elsewhere in Pennsylvania as being of Illinoian age. The coloration and weathering is presumably the result of weathering under more humid and temperate conditions than now exist in Pennsylvania during the Sangamonian interglacial between the Illinoian and Wisconsinan glaciations. The lower gray till appears to be totally unweathered. The gray till locally overlies saprolite developed in the sandstones, siltstones, and shales of the underlying bedrock.

The critical problem involved with this sequence is the contact between the yellow (middle) and gray (lower) till. This contact appears to be a mechanical contact and not the base of a weathering zone. Because of this problem, as yet unresolved, several interpretations of the sequence are possible.

1. The gray till is pre-yellow till in age and thus may be the result of Kansan, Nebraskan or an earlier Illinoian glaciation. The yellow till was deposited by the last Illinoian glacial advance, was subjected to Sangamonian weathering, and the sharp contact with the underlying till is coincidental. The upper brown till was deposited by the Woodfordian glaciation which removed most of the Illinoian till.

2. The yellow till is a result of Illinoian glaciation and Sangamonian weathering. The gray till was deposited by an Early Wisconsinan (Altonian) glaciation and the yellow till is a large erratic mass included in the gray till. The brown till was deposited by the Woodfordian glaciation which eroded any gray till which may (or may not) have been above the yellow till erratic mass.

3. The yellow till is a result of Illinoian glaciation and Sangamonian weathering. The gray till was deposited by a lobe of Woodfordian ice and the yellow till is a large erratic mass included in the gray till. The brown till was deposited by another (and later) lobe of Woodfordian ice which

eroded any gray till which may (or may not) have been above the yellow till.

4. The yellow till is a result of Illinoian glaciation and Sangamonian weathering. The gray and brown tills are the result of the same ice advance and the yellow till is an erratic mass included within the deposit. The color difference between the brown and gray tills is the result of oxidation of the upper (brown) till which was originally gray just like the lower till.

In summary: Unfortunately, the first exposure (now lost to further study because of backfilling) of multiple tills in the glaciated area of eastern Pennsylvania is not simple.

LEAVE STOP 8 and CONTINUE on route 58012 (TURN RIGHT at entrance).

0.5	24.1	Small outcrop of Burgoon Sandstone on right.
0.4	24.5	Outcrops of Huntley Mountain Formation on right.
0.6	25.1	BEAR LEFT at road fork to junction with PA Route 287 and TURN LEFT onto PA Route 287 north.
0.6	25.7	Crossing Rattler Run.
0.5	26.2	Crossing Basswood Run.
1.4	27.6	Delmar Township line.
0.4	28.0	Site of STOP 6 (Day 1) on left.
5.4	33.4	View ahead and to right of a through valley which served as a Woodfordian glacial spillway.
1.7	35.1	Wellsboro Borough limit.
0.9	36.0	STOP LIGHT (usually blinking). TURN RIGHT onto Grant Street and proceed straight.
0.2	36.2	STOP LIGHT. TURN RIGHT onto U. S. Route 6 and PA Route 660.
0.5	36.7	Corning Glass Plant on left; All "Shiny Brite" (Tm) Christmas ornaments were made here. Penn Wells Hotel lobby glass flag came from here.
1.5	38.2	Outcrop on right; Lock Haven Formation sandstone and some shale.
0.7	38.9	Outcrop on right; evenly interbedded siltstone and shale of Lock Haven Formation. NOTE: Willard (1932) lists five outcrops along Route 6 and their faunules as his Locality 20. His outcrops east of Wellsboro occur at 2.7 miles, 2.9 miles, 3.8 miles (thin bed of hematite), 5.4 miles, and 5.7 miles (some hematite). The outcrop here would be his faunule 53b site.

0.2	39.1	Outcrop on right of shale with some thin siltstone beds, Lock Haven Formation.
0.4	39.5	Outcrop on right; shales of Lock Haven Formation.
0.4	39.9	Crossroads; About 0.8 miles to the north the "Arieno Shaft" was sunk on the creek bank. Ten to twenty thousand dollars was spent looking for anthracite coal in "Chemung" rocks (Sherwood, 1878). Road to left leads to Hills Creek State Park.
0.9	40.8	Outcrop on right of dark brown shale and some siltstone beds (near top of outcrop); Lock Haven Formation.
1.4	42.2	Junction of U. S. Route 6 and PA Route 660. CONTINUE STRAIGHT ahead on U. S. Route 6.
2.4	44.6	Roadcut through fossiliferous interbedded siltstone and shale, and some thin sandstone beds of the Lock Haven Formation.
0.8	45.4	Outcrop on left of dark brown shale overlain by very thin oolitic iron ore, followed by thin-bedded siltstone and sandstone, all Lock Haven Formation. Loadcasts at east end of outcrop. Very fossiliferous.
0.7	46.1	Outcrop on right of dark brownish gray shale and interbedded thin siltstones of the Lock Haven Formation. Fossiliferous. Some pencil siltstone.
0.4	46.5	TURN LEFT onto Orebed Road.
0.1	46.6	TURN LEFT following Orebed Road.
0.6	47.2	STOP 9. Mansfield Ore Bed. Discussant: P. B. Luce. Buses turn around in adjoining field.

Introduction

The Mansfield Ore Bed lies approximately 200 ft below the top of the "Chemung". The second bed lies 200-400 ft below the upper bed and is separated stratigraphically from the lower bed by 100-200 ft of strata. (Sherwood, 1878).

Sherwood's (1878) criteria for recognition are:

Mansfield Ore Bed - no fish fossils; *Spirifer* and *Productus* [*Spirifer disjunctus* and *Productella lacrymosa* (Williams and Kindle, 1905].

Middle Bed - fish fossils; oolitic

Lower Bed - fish fossils; small flattened quartz pebbles (1 locality reported).

However, oolites are found at this outcrop as well as fish plates and scales (tentative identification). More oolitic horizons have been found in the Lock Haven Formation.

The character of the ores changes laterally. Sherwood (1878) identified the first bed at the confluence of Seeley Creek and Lambs Creek. At this locality the ore is in a ferruginous sandstone, but it is structurally equivalent. The Whipple Hill and Mann's Creek ore beds are similarly equivalent to the Middle bed, but the Whipple Hill material is a ferruginous sandstone and poorly oolitic, if at all. Calculated dips at 2° between outcrops agrees with the measured 2°N dip (strike N75E) at this stop. That these 4 occurrences are discrete is suggested further by the fact that no ore bed outcrops occur where projected dips intersect the topography.

Geometry of the Ore Bed

The deposit at this top is inferred to be lenticular. An excavation, oriented roughly north-south, exposed a fossil horizon descending toward the presumed lentil long axis which is oriented east-west. That the attitude of the fossil horizon is not structural is shown by the undeformed sharp contact with the overlying mud stone. The ore can be seen in the ditch at the stop entrance and ascending up the road to the west, but it does not appear beyond the hill crest.

Ore

The ore is extremely similar to the well-known Clinton iron ores (Lower Silurian). It has spherical ooids, flattened ooids (flax-seed), and fossils replaced by hematite. Flattened ooids have been observed rolled together into spherules up to 3 mm in diameter. Park and MacDiarmid (1964) consider the Clinton ores to be early diagenetic replacements of calcareous ooze, fossil fragments, and ooids with additional direct hematite precipitation in a shallow marine environment. They further state (p. 368) that when aerated river waters having a pH of 7 or lower and carrying significant quantities of ferrous iron, enter the marine environment, "the iron will be precipitated as ferric oxide, both in the water and as a direct replacement of the calcium carbonate."

The origin of oolites, as $CaCO_3$, and their concentration calls for repeated agitation in situations such as offshore shoals awash at low tide (Mathews, 1974) or tidal deltas (Selley, 1976). The inferred geometry of the deposit at this stop favors the latter situation because the overlying beds appear to be tidal flat deposits. This situation implies a shoreline oriented approximately N-S where maximum agitation in the depression would occur along the major axis of the tidal delta which would be generally perpendicular to the shoreline.

Questions to be entertained at this stop include: (1) Where was the shoreline? (2) Do the sporadic accumulations of iron ores have any structural control? (3) Why do we find both usable ore deposits and ferriginous sands as presumable equivalents?

LEAVE STOP 9 and retrace route to U. S. Route 6.

0.7	47.9	STOP SIGN. TURN LEFT onto U. S. Route 6 east.
1.9	49.8	Old Mansfield Iron Furnace was located just to the south.
0.1	49.9	Tioga River; Rip-rap is Pottsville sandstone quarried at Brownlee.
0.2	50.1	STOP LIGHT; Intersection of U. S. Routes 15 and 6 in Mansfield. TURN LEFT onto U. S. Route 15 north.
1.6	51.7	Outcrop of Lock Haven Formation on right.
0.3	52.0	Crossing Kelly Creek which is Willard's (1932) Locality 23.
1.3	53.3	Slump scar on right exposes Olean Till (Woodfordian). Sandy tills here and elsewhere in the state are susceptible to landsliding, particularly when natural slopes are modified and water is added.
0.4	53.7	Outcrop of Catskill Formation on right. Cut slope is unstable.
1.0	54.7	Slump scar on right exposes Olean Till.
0.6	55.3	View of Tioga Lake on left.
0.6	55.9	Crossing Mill Creek which is Willard's (1932) Locality 22. Borrow area on lake shore to right.
0.6	56.5	Outcrop of Catskill Formation on right.
0.9	57.4	View of Tioga and Hammond Lakes, Tioga Dam, and connecting channel on left. Grassed landslide scar on right. A major landslide occurred here during highway relocation and dam construction. It was one of the largest in Pennsylvania. See discussion at Stop 12.
0.3	57.7	Outcrops of Catskill Formation on both sides.
0.6	58.3	<u>STOP 10.</u> Lock Haven and Catskill Formations. Discussant: D. L. Woodrow. Park on berm on right side of road just south of covered interval at base of mixed red and gray sequence.

Strike: N85W; dip 5SW

Stratigraphy

The Pennsylvania Geological Survey assigns these rocks to the Lock Haven and Catskill Formation (Berg and others, 1980). The contact between the two is located in or just at the top of the covered interval (64-82 m, Figure 34). Relating these rocks to the New York section is less certain but, based on physical criteria, it appears that the dark gray shale

ROADCUT, US RTE. 15 - TIOGA, PA.

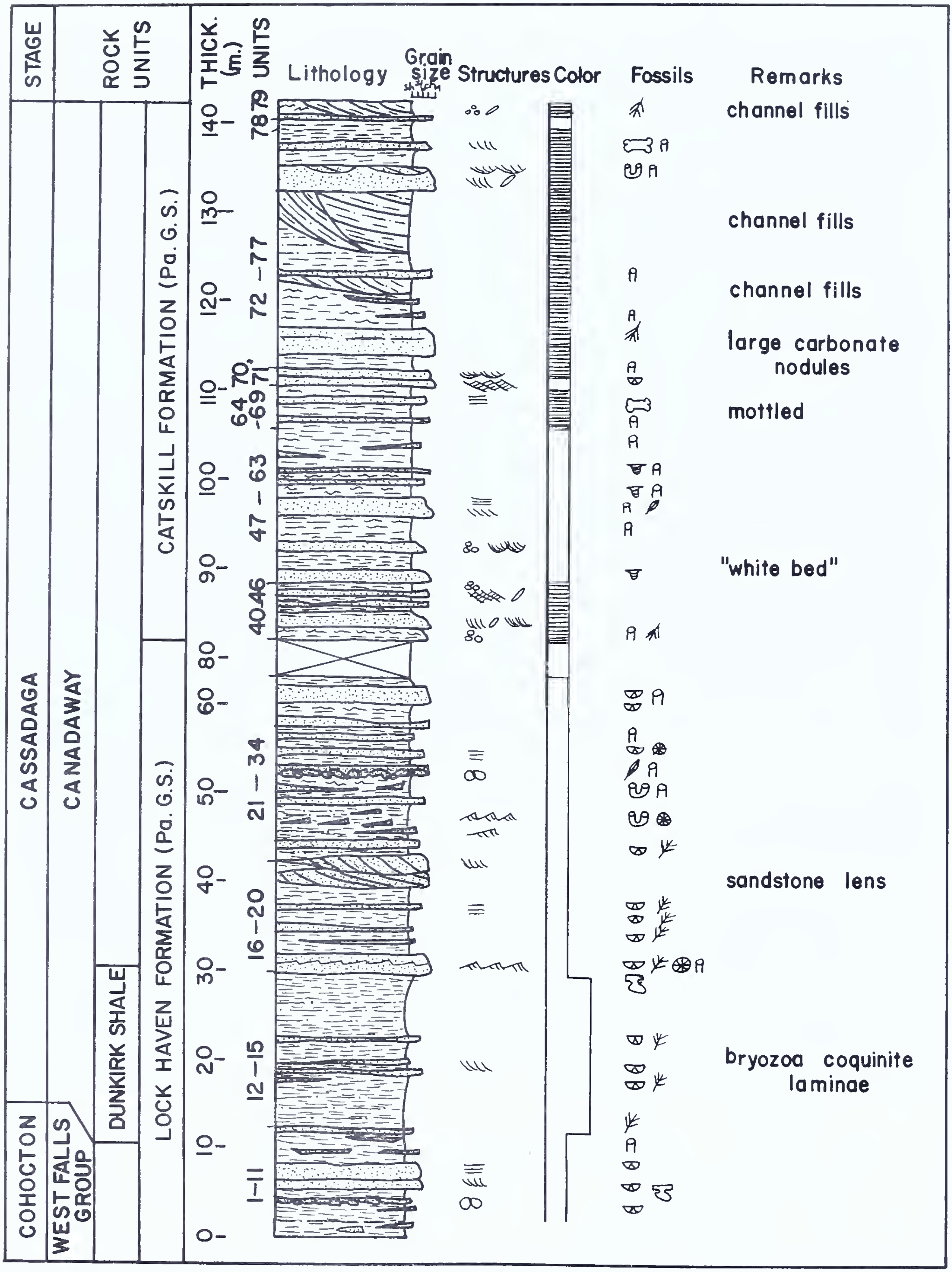


Figure 34. Stratigraphic column of Lock Haven and Catskill Formation rocks exposed along U.S. Route 15 near Tioga, Pennsylvania. (see Figure 26 for key).

sequence (units 12-15) represents the Dunkirk Shale of the Canadaway Group. If so, then the base of the shale sequence is the contact between the West Falls Group below and Canadaway Group above. That boundary, if correctly placed, also represents the Frasnian/Famennian Stage boundary in this sequence (Rickard, 1975).

Lithology and Sedimentary Structures

The sequence is divisible into 4 parts: (1) a gray sandstone-shale sequence at the base (units 1-11), (2) dark gray shale with thin coquinites (units 12-15), (3) gray sandstone, shale and thick coquinites (units 16-39) and, at the top, (4) a mixed sequence of red and gray sandstones, shales, mudstones, and siltstones (units 40-79). Sandstones are thick-bedded, fine- to medium-grained, and red in the upper subdivision and sandstones are thin-bedded, fine-grained, and gray in the lower three subdivisions. Shales found with the gray sandstones tend to be fissile; those found with the red sandstones are heavily bioturbated. Most of the sandstones show great variation in thickness, unit 20 lensing out completely for example, and units 49 (the "white bed") thinning from 3 m to 1 m across the exposure. Distinctive red, thick (up to 5.5 m thick) channel-fill siltstones and sandstones are found in units 74 and 79.

Variations in sedimentary structures are also seen in vertical sequence. Sandstones in the lower 3 subdivisions show various scour marks with orientations ranging from 250° to 315°. Most of these sandstones are horizontally laminated with cross-laminae in the current or interference ripples found on their upper surfaces. Rarely do these sandstones extend more than 10 m across the exposure. Many appear to be very thin channel fills. Ball-and-pillow structures are found at only 2 horizons (units 1 and 24). In the upper subdivision, trough cross-bedding, and drape-like channel fills are developed. Gravels of shale fragments and carbonate nodules are found in several of the sandstones (units 53, 59, 75 and 79). Carbonate nodules, _in situ_, are found in red mudstones and red sandstones (units 40, 48, 73).

Unit 49 (the "white bed") is the most distinctive bed of the exposure. It is a light gray weathering, fine-grained, massive sandstone with brown weathering, dolomitic (ankeritic?, sideritic?) zones throughout. The same bed is exposed in the left (west) abutment of the Tioga dam and in the wall of the connecting channel between the 2 reservoirs (see Stop 12). Rocks in the upper subdivision are dominantly red and they form the base of a nearly unbroken red sequence tens of meters thick which extends south along U. S. Route 15. That higher red sequence was not measured for this trip.

Fossils

Shelly invertebrates are the most common fossils seen. _Cyrtospirifer_ sp. _Athyris_ sp., _Camarotoechia_ sp., and _Productella_ sp. have been identified. Bivalves, crinoids, and bryozoans also are represented. The bryozoans are a distinctive feature of the lower subdivisions. They occur as fragmental material in laminae, lenses, and thin coquinites. Above the shale sequence, the bryozoans are found with tiny crinoid columnals.

Plant fragments occur both as tiny, fine fragments, and large pieces of coalified wood. Well preserved impressions of roots are found in units 41 and 73. Fragments of bone and fish plates have been found in the upper parts of thicker sandstones toward the top of the sequence.

Trace fossils are conspicuous in these beds. Small, vertical burrows (*Trichichnus*) and *Planolites*-like horizontal burrows are found in many of the sandstones and shales of units 1-10. Some of the shales in the lower subdivisions are completely disrupted by bioturbation (base of unit 12, units 18, 22, 23, 32). The greatest variety of trace fossils is seen in the upper subdivision where the stubby vertical burrow with spreiten, *Teichichnus*, two varieties of u-shaped burrow (*Arenicolites* and *Diplocraterion*), and the vertical burrows *Skolithos* and *Trichichnus* are found. Individual sandstones in the upper subdivision are so completely perforated by the vertical burrows that the internal plan of the bed is disrupted.

Interpretation

As can be seen from the log and the description, this is a complicated sequence. Analysis of it is at an early stage, so the interpretations must be viewed as tentative. It seems clear, however, that a record is preserved here (from the base of the section to the top) of deposition in increasingly shallow water. At the base, the sandstone characteristics, the diversity of the fauna and the relatively broad extent of individuals beds suggest deposition on the open sea floor with occasional incursions of sand and silt from an advancing delta-front (units 6-9, 20, 24). Many of the individual sandstone beds have sharp basal contacts, gradation upward into mudstone, and limited lateral extent, all of which suggest the effect of storms on the sea floor.

The upper subdivision offers great contrasts with the rocks below. Many of the strata in the upper subdivision were deposited in shallow water and others among them were deposited subaerially or were exposed to the atmosphere before lithification. Indicative of the shallow water deposition is the presence of many kinds of trace fossils, climbing ripples, and quantities of large plant fragments. At the same time, *Lingula* sp. is the only invertebrate found. That some of these beds were exposed to the atmosphere is indicated by root impressions and by what appear to be pedogenic carbonate nodules. The thick channel-fills in unit 74 also may indicate subaerial exposure. These channel-fills may represent the draped infilling of a pre-existing channel, perhaps an ox-bow. Some of the individual beds in the channel-fill appear to be graded, suggesting waning-flow deposition during a flood.

Deserving of special mention is the white-weathering sandstone (unit 49) and the rock sequence directly above and below it. The rocks below display climbing ripples, plant impressions and *in situ* carbonate nodules, all features which suggest subaerial deposition: the climbing ripples in a levee or crevasse splay, and the root impressions and carbonate nodules in the interfluves. The sandstone itself is a fine-grained, well-sorted quartz sand. Above it is a sequence of bioturbated, plant-fragment bearing sandstones and shales. The sequence suggests 3 stages of development. First, a small distributary lobe developed on it with shallow, levee-bounded channels

and interfluves with swamps, the whole surface desiccated most of the time. Abandonment of the distributary lead to transgression and development of a transgressive beach/bar complex trailing a sheet sand behind it. The sands apparently result from winnowing of the sediment on the distributary surface by the advancing sea. With continued transgression, the lobe and its quartz sand cover were buried under brackish or marine muds deposited in an interdistributary bay.

LEAVE STOP 10 and CONTINUE north on U. S. Route 15.

0.3	58.6	Base of exposed Lock Haven Formation on right.
0.1	58.7	Landslide in Olean Till on left. Water seepage occurs in middle and toe of slope. Drainage ditch is ineffective in halting seepage.
1.4	60.1	STOP SIGN. TURN LEFT onto PA Route 287 south. Now travelling on Tioga River outwash plain.
0.9	61.0	Crossing Tioga River.
1.2	62.2	STOP SIGN. TURN RIGHT following PA Route 287 south in center of Tioga.
1.5	63.7	Crossing Elkhorn Creek. At the mouth of Elkhorn Creek is Willard's (1932) Locality 9. Locality 10 runs north up the creek valley.
0.1	63.8	Outcrops of Lock Haven Formation on both sides are part of Stop 11.
1.4	65.2	View of Ives Run alluvial fan to left across lake.
1.2	66.4	TURN LEFT to Ives Run Recreation Area.
0.5	66.9	Cross Crooked Creek. CONTINUE on main road avoiding turns. Road winds through the Ives Run Recreation Area picnic grounds and crosses the center of the Ives Run alluvial fan.
1.2	68.1	LUNCH. Lakeside Pavilion. The basic purpose of this stop is to ingest food. However, some comments will be made about the Tioga-Hammond Project and the alluvial fan.

LEAVE Lakeside Pavilion and retrace route to PA Route 287.

1.7	69.8	TURN RIGHT into PA Route 287 north. Outcrop of Catskill Formation on left.
0.9	70.7	View of Ives Run alluvial fan to right across lake.
1.5	72.2	TURN LEFT to Hammond Lake overlook.

0.2 72.4 Outcrops of Lock Haven Formation on both sides are part of Stop 11.

0.2 72.6 TURN RIGHT into Hammond Lake overlook parking.

STOP 11. Lock Haven Formation. Discussant: T. M. Berg. This stop involves a 0.9 mile walk down through outcrops below the overlook and along PA Route 287, across the railroad, and down to the Hammond Dam emergency spillway.

Before bedrock exposures are examined, the excellent view of the valley choker moraine in the valley of Crooked Creek should be noted. G. H. Crowl or W. D. Sevon may make comments here.

The marine sequence exposed here is divided into two parts: Stop 11a and Stop 11b. The upper part is located in the horseshoe curve access road leading to the overlook and is Stop 11a. The stratigraphic section at 11a is illustrated in Figure 35. The lower part is the long road cut along PA Route 287 (southeast side of road) and is Stop 11b. The stratigraphic section at 11b is illustrated in Figure 36.

This part of the Lock Haven Formation is located about 75 m (250 ft) below the Catskill Formation mapped in this area. As such, the exposures are at about the same general stratigraphic position as the Luthers Mills coquinite (see Stop 1). Indeed, some of the brachiopod-rich beds in the upper part of the 11b section are somewhat reminiscent of the Luthers Mills.

Stop 11a

The principal features to be observed in the section at 11a are the large load cast structures, the dominant megaripple or sand wave bed form in the sandstones, and the apparent arrangement of the sequence in three cycles. A typical cycle appears to be marked at first by an influx of sand which foundered into muddy beds of a previous cycle. The resulting load-casted zone at the base of a cycle is followed by a second component marked by continuous sand deposition, arranged as overlapping megaripples or sand waves. Note that the sandstone beds are brownish gray. The sandstones contain fossils as indicated in Figure 35. The base of the sandstone bed just below 5 m contains some scattered oolites and is quite hematitic. The sandstone is succeeded in the cyclic progression by a third component including medium-gray siltstone, silt shale, and sand-silt laminite; some thin, planar-bedded sandstone interbeds are present.

The marine cycles observable in Stop 11a may be the result of delta distributary switching, shoreward and landward from these outcrops. They may also represent storm-generated sand influxes, followed by gentle wave-generated current reworking, followed by relatively quiet, shallow shelf sedimentation.

Stop 11b

The long sequence exposed in the road cut at Stop 11b (Figure 36) represents a more complex suite of depositional environments.

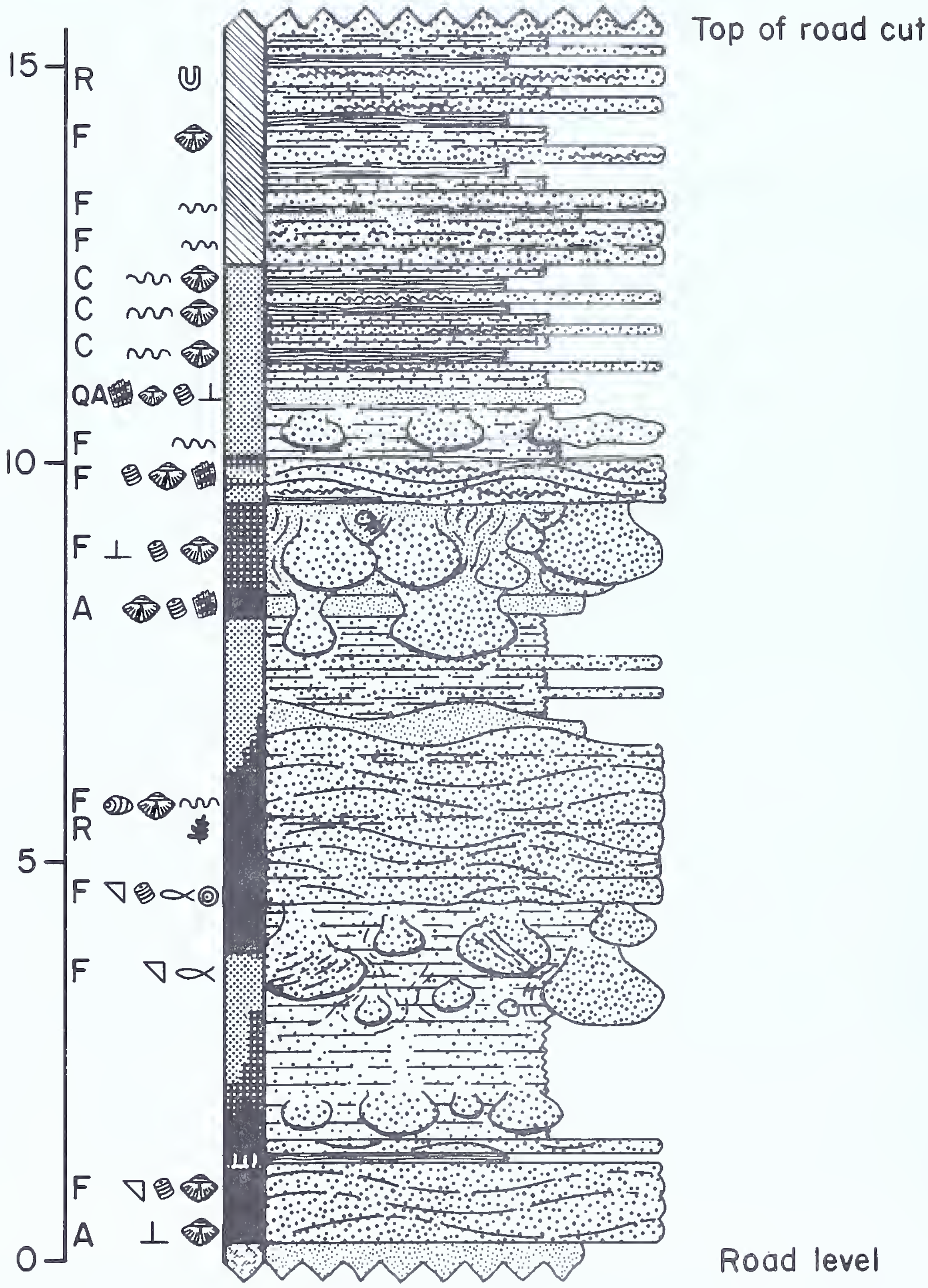


Figure 35. Columnar section showing marine sequence in Lock Haven Formation at Stop 11a. Key is on page 157.

The upper 15 m of section (from 44 to 29 m, Figure 36) is a succession of apparent cycles characterized by massive, brachiopod-rich, brownish-gray sandstone or siltstone, overlain by and grading up to thinner-bedded siltstone having silt shale interbeds (Plate 9A). The thick, brachiopod-rich, siltstone/sandstone beds are crossbedded, apparently the result of migrating sand waves (Plate 9B). Some cut-and-fill structure is evident (Plate 9C). One of the thick siltstone beds (at 41 m, Figure 36) contains a large fish bone fragment (Plate 9D). The cycles differ from those exposed at Stop 11a in that load casting is not prominent, and brachiopod accumulations are much thicker, and well developed. Could these cycles be the result of storm-generated tidal channel deposition?

The thick, massive, brownish-gray siltstone at 29.0 to 27.5 m (Figure 36) is unique and should serve as a very interesting topic for discussion. The siltstone has abundant spiriferid brachiopods concentrated at the base. Scattered throughout the siltstone are "balls" of siltstone or mudstone, also brownish gray, which seem to have foundered within the massive bed. Could this unit represent a single storm-generated mudflow in a tidal delta complex?

The interbedded sequence down to 17 m (Figure 36) is a mixture of siltstone, silt shale, clay shale, sand-silt laminite, and some thin-bedded sandstone. Concentrations of brachiopods and other fossils (crinoid columnals, bryozoans) are common. This appears to be a sequence of shallow marine shelf deposits. Megaripple bedding hints at the likelihood of deposition within the reach of wave base.

The light-gray sandstone at 17 to 15 m (Figure 36) is another unit that should spark considerable discussion. The sandstone is fine grained, having thin, grayish-black silty clay shale interbeds. The bottoms of individual sandstone beds weather moderate brown. Scattered clay chips are common, especially in what appears to be a tidal channelway. Sandstone beds range from 4 to 42 cm thick. Abundant burrows including <u>Arenicolites</u> and hypichnial ridges and exichnial burrow casts occur within this sandstone(Plate 8F). It is interpreted to be a tidal sandflat deposit. Individual beds broadly overlap each other, indicating migration of the sandflat towards the northeast.

The succession to the end of the road cut and the bottom of the section includes shales, siltstones, and sandstones that seem to speak of quieter-water conditions in general, and may represent a mixture of lagoon and lagoon channel deposits. Of particular interest is the occurrence of the bivalve, <u>Grammysia</u> at 12.5 to 12.0 m (Figure 36). Burrowing and trace fossils in the sandstones near the bottom of the section may represent a return to more nearshore, wave-affected conditions.

Apologies are extended to those who don't like to think "down-section" but the downhill walk was easier wasn't it?

On this Field Conference, attendees will be picked up at the Hammond Dam emergency spillway and transported to Stop 12 via roads not open to the public. The following road log is the route via public roads.

LEAVE Hammond Lake overlook parking and retrace route to PA Route 287.

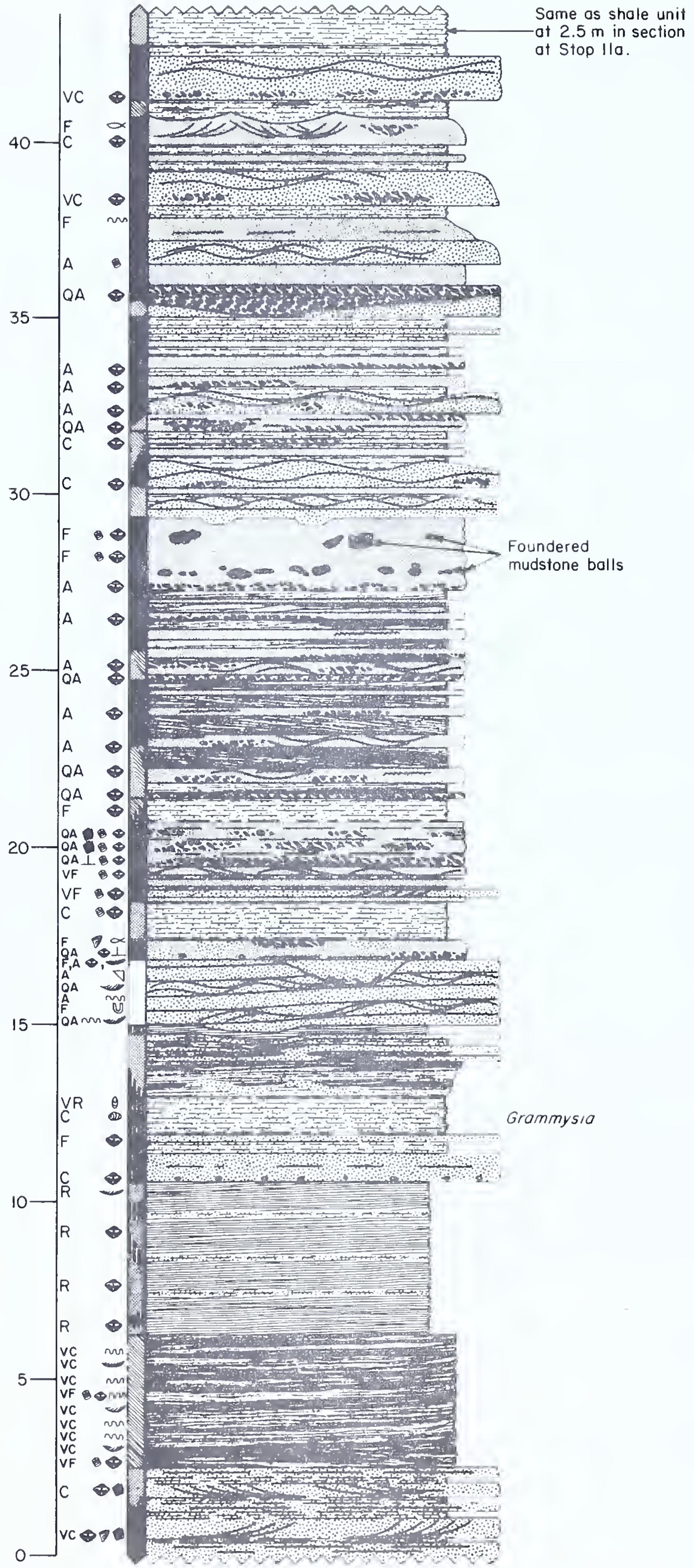
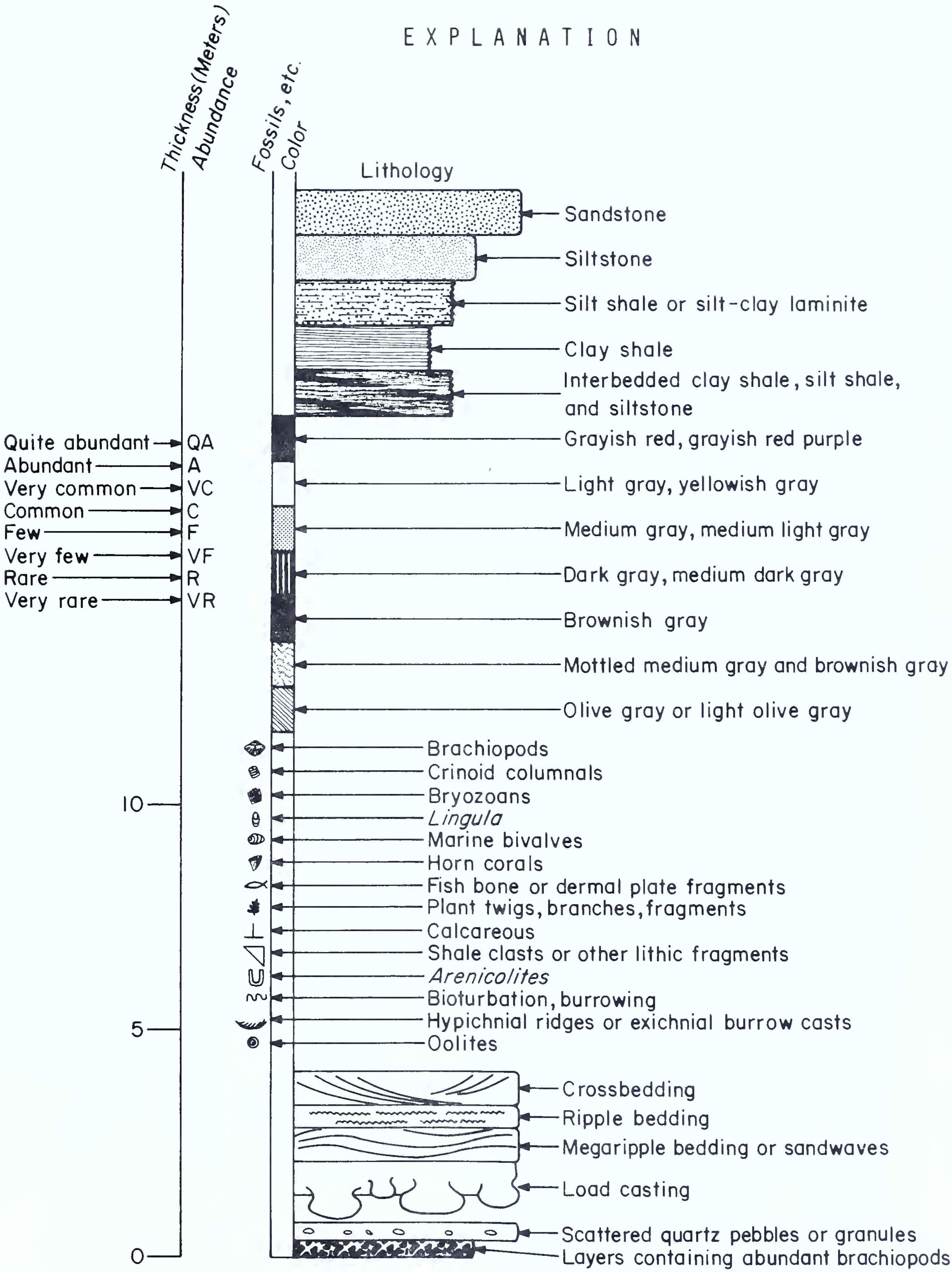


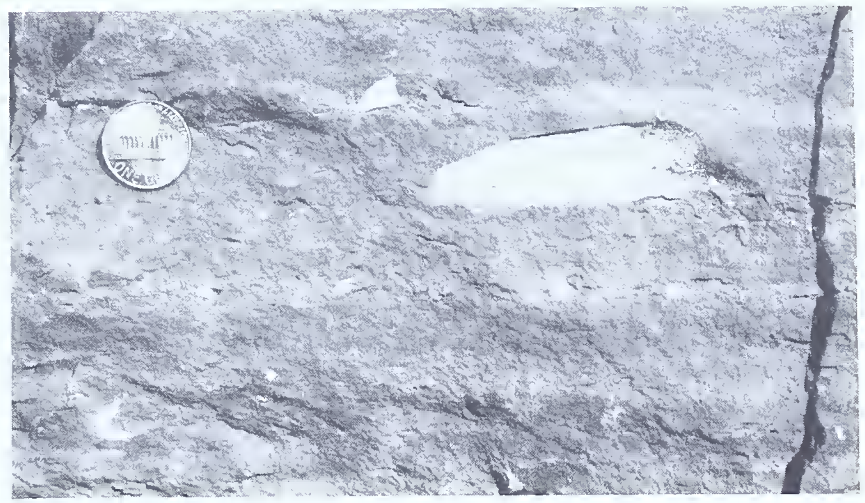
FIGURE 36. COLUMNAR SECTION SHOWING MARINE SUCCESSION IN LOCK HAVEN FORMATION AT STOP 11B. KEY IS ON FACING PAGE.


EXPLANATION
Thickness (Meters)
Abundance
Fossils, etc.
Color
Lithology
Sandstone
Siltstone
Silt shale or silt-clay laminite
Clay shale
Interbedded clay shale, silt shale, and siltstone
Grayish red, grayish red purple
Light gray, yellowish gray
Medium gray, medium light gray
Dark gray, medium dark gray
Brownish gray
Mottled medium gray and brownish gray
Olive gray or light olive gray
Quite abundant QA
Abundant A
Very common VC
Common C
Few F
Very few VF
Rare R
Very rare VR
10
5
0
Brachiopods
Crinoid columnals
Bryozoans
Lingula
Marine bivalves
Horn corals
Fish bone or dermal plate fragments
Plant twigs, branches, fragments
Calcareous
Shale clasts or other lithic fragments
Arenicolites
Bioturbation, burrowing
Hypichnial ridges or exichnial burrow casts
Oolites
Crossbedding
Ripple bedding
Megaripple bedding or sandwaves
Load casting
Scattered quartz pebbles or granules
Layers containing abundant brachiopods

A. Base of cycle; 35m in Figure 36; hammer for scale.

B. Brachiopod bed and sand waves; 41m in Figure 36.

C. Brachiopods, fish bone (at hammer), and cut-and-fill structure; 41m in Figure 36.



D. Fish bone (scale = penny); 41m in Figure 36.

PLATE 9

0.5		TURN LEFT onto PA 287 north.
2.0		TURN RIGHT on S. Main Street at the center of Tioga and follow road to Tioga-Hammond Lakes overlook. PA Route 287 turns left here.
0.4		View of Tioga Dam straight ahead.
1.4		Tioga-Hammond Lakes overlook and parking. Visitors not on this Field Conference will view Tioga Dam and the connecting channel from here because sites visited on this trip are not generally open to the public.

The following is the road log used for this Field Conference.

Buses LEAVE Hammond Overlook parking. TURN LEFT. Pass through road cut in upper Lock Haven Formation. TURN LEFT at STOP SIGN onto PA 287 north.

1.3	73.5	TURN sharp RIGHT onto gravel road just past red barn.
0.3	73.8	Cross bridge through gate. TURN RIGHT off road into Hammond spillway. Participants REBOARD BUSES here when finished with Stop 11.
0.1	73.9	TURN RIGHT on gravel access road from spillway parking.
0.1	74.0	Downstream toe of Hammond embankment.
0.1	74.1	Continue up embankment face to top of dam. Valley choker moraine on right covered with dense growth of evergreens.
0.2	74.3	Road to right onto choker moraine. CONTINUE STRAIGHT along dam axis.
0.1	74.4	Borrow area for embankment fill across lake on right.
0.2	74.6	Cross Hammond outlet works. Note erosion of valley choker moraine at 5 o'clock. Shoreline erosion here has been a continuous problem.
0.3	74.9	Gate. STOP, then TURN RIGHT on paved road.
0.3	75.2	Pass Tioga-Hammond Overlook Parking on right and proceed through gate.
0.1	75.3	Outcrop of Lock Haven-Catskill Formations transition beds on left.
0.1	75.4	TURN onto Tioga Dam embankment at left abutment.
0.1	75.5	Tioga-Hammond control tower and gates.

0.1 75.6 STOP 12-A. Tioga Dam and Landslide. Discussant: J. P. Wilshusen. Disembark on Tioga embankment. Discussion of geology of dam sites, dam construction, and the occurrence and repair of major landslide above right (east) abutment. Note Stop 9 at 10 o'clock. See pages 77-90 for text discussion and diagrams.

Reboard buses.

Descend upstream face of Tioga Dam embankment to base of control tower and gates.

0.2 75.8 Road cut on right is in uppermost Lock Haven Formation.

0.2 76.0 STOP 12-B. Connecting channel. Disembark and gather between guardrails on weir crest. Use caution. Please leave rock hammers on the bus; the Corps of Engineers has requested that we use no hammers on rock exposures here. Discussants: W. D. Sevon, J. P. Wilshusen, and Representative from Corps of Engineers.

Further aspects of the Tioga-Hammond Dams will be discussed. See pages 77-90 for text discussion and diagrams.

Rocks exposed at the Tioga-Hammond Dams connecting channel include the upper part of the Lock Haven Formation and the lower part of the Catskill Formation. Fossiliferous, planar-bedded siltstones and shales of the Lock Haven are well exposed along the road leading to the connecting channel. A red siltstone-claystone occurring in the upper part of this sequence and exposed at the south end of the Hammond weir marks the base of the Catskill Formation. Excellent views of the lower part of the Catskill occur on both sides of the connecting channel.

Bedding surfaces of the basal red bed of the Catskill Formation exposed at the south end of the Hammond weir contain several types of ripple marks and numerous burrows of various size. Above this is about 1 m of gray siltstone and shale. The siltstone is somewhat massive and extensively burrowed. The burrowed areas are calcareous and weather brown. Overlying the gray unit is gray, very slightly calcareous, apparently structureless, very well sorted, fine grained sandstone. The unit contains some vertical burrows. The long exposure of this unit along the connecting channel shows large scale irregular bedding. This sandstone correlates with the "white bed" (unit 49) of Stop 10. The interpretation here is presumably the same as that at Stop 10.

LEAVE Stop 12-B.

0.2 76.2 Base of control structure.

0.1 76.3 BEAR LEFT at fork up embankment.

0.2 76.5 TURN sharp LEFT on crest of dam.

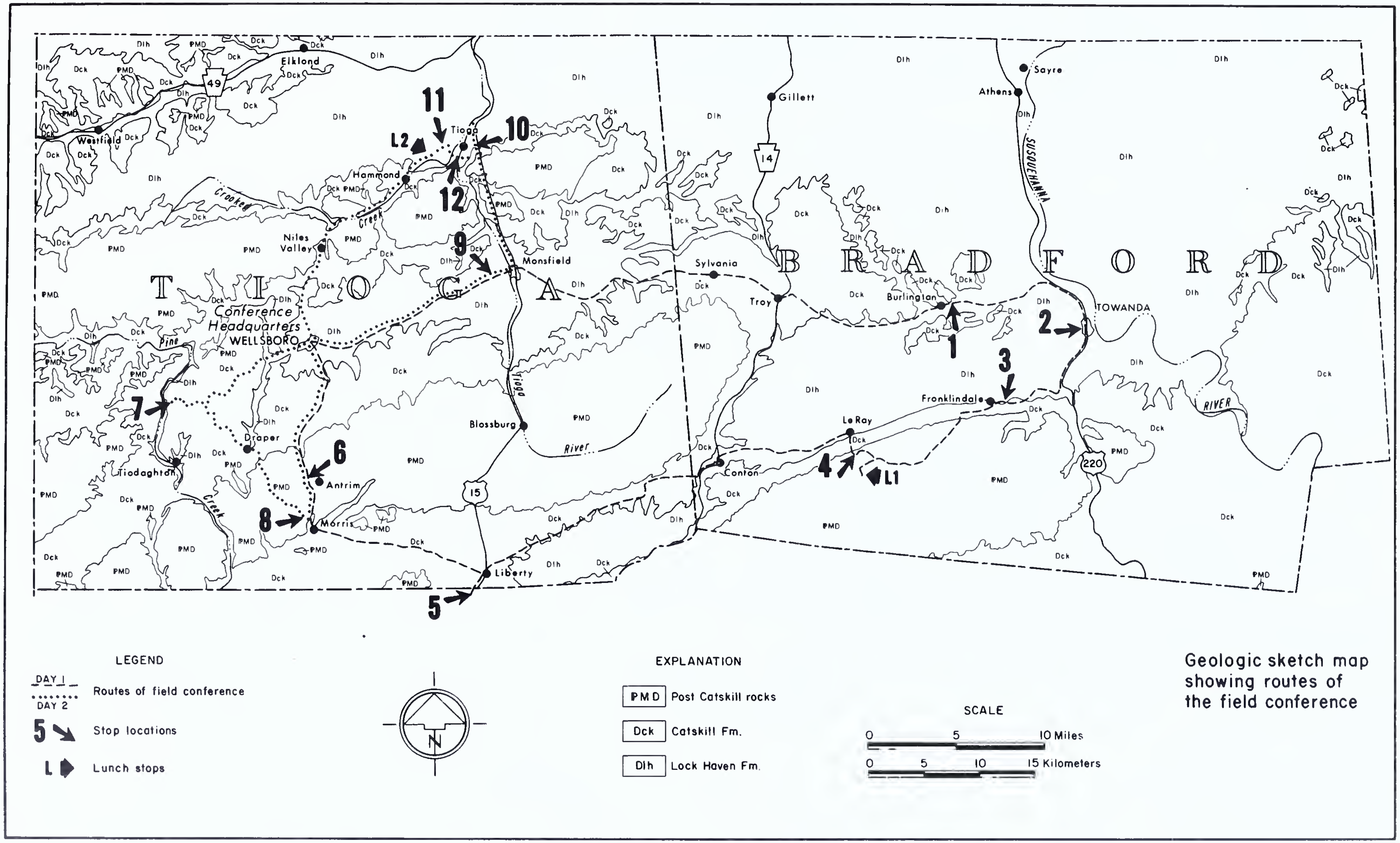
0.5	77.0	Gate at Tioga overlook, CONTINUE STRAIGHT ahead.
0.4	77.4	Pass Hammond access road on left. CONTINUE STRAIGHT, following paved road.
0.8	78.2	Tioga Dam outlet channel on right. Channel cut is in the Lock Haven Formation.
0.2	78.4	TURN LEFT.
0.4	78.8	TURN LEFT on PA Route 287 at STOP SIGN in center of Tioga.
1.3	80.1	Railroad underpass.
0.6	80.7	Entrance to Hammond overlook on right.
2.4	83.1	Tioga-Hammond Park entrance on left.
1.5	84.6	Abandoned borrow area on right.
1.2	85.8	Village of Crooked Creek. Road to Hills Creek State Park on left.
0.8	86.6	Valley side kame on right.
0.3	86.9	Cross Crooked Creek.
1.1	88.0	Village of Middlebury Center, intersection PA Route 249. CONTINUE STRAIGHT on PA Route 287.
0.7	88.7	Kame on right.
0.6	89.3	Quarry in Devonian Catskill Formation on hilltop to left. All sizes of material for use as road metal are crushed here.
0.3	89.6	Approximate drainage divide between Norris Brook which flows into Crooked Creek and Marsh Creek which flows into Pine Creek (Figure 8). During high water periods the area drains in both directions.
0.4	90.0	Delmar Township line.
0.6	90.6	Kame moraine on right in area known locally as the "hogbacks".
0.4	91.0	Travelling on outwash plain.
1.5	92.5	Cross railroad tracks.
0.2	92.7	STOP SIGN. TURN LEFT on U. S. Route 6 east and PA Route 287 south.
0.1	92.8	Outcrop following old U. S. Route 6 on right is Locality 11 of Willard (1932) (partially obscured by trees.)

0.6	93.4	Outcrop of Lock Haven Formation on right.
0.7	94.1	Kame deposit on right behind barn.
0.3	94.4	Borough of Wellsboro boundary.
0.9	95.3	STOP LIGHT. CONTINUE STRAIGHT.
0.1	95.4	TURN RIGHT into Penn Wells Hotel parking lot. End of Day 2.

HAVE A SAFE TRIP HOME!!

Travel Time Between Stops

	Minutes
Wellsboro to Stop 1	50
Stop 1 to Stop 2	15
Stop 2 to Stop 3	16
Stop 3 to Lunch 1	29
Lunch 1 to Stop 4	8
Stop 4 to Stop 5	46
Stop 5 to Stop 6	20
Stop 6 to Wellsboro	12
Wellsboro to Stop 7	23
Stop 7 to Stop 8	39
Stop 8 to Stop 9	30
Stop 9 to Stop 10	10
Stop 10 to Lunch 2	23
Lunch 2 to Stop 11	10
Stop 11 to Stop 12	10
Stop 12 to Wellsboro	30



Geologic sketch map showing routes of the field conference